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SOUTH AUSTRALIA

TECHNICAL REPORT

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TRANSMISSION OF INFRARED RADIATION THROUGH THE AUSTRALIAN ATMOSPHERE: PREDICTIONS USING THE LOWTRAN MODEL

G.A. FINDLAY and D.R. CUTTEN

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TRANSMISSION OF INFRARED RADIATION THROUGH THE AUSTRALIAN ATMOSPHERE: PREDICTIONS USING THE LOWTRAN MODEL

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SUMMARY

This report investigates the applicability of the standard LOWTRAN atmospheric models to four typical Australian environments and considers the effect of these environments upon the transmission of 3 to 5 μm and 8 to 12 μm radiation. It is found that the LOWTRAN model atmospheres can be useful in Australian conditions, and advice is given as to the most appropriate models to use depending upon the path and environmental conditions. The extent to which model data is used rather than real data will affect the transmittance predictions; the magnitude of this effect is given, indicating that there is particular value in measuring water vapour content (shown to be the most significant meteorological parameter) in the lowest few kilometres through which the path passes. Transmittance as a function of range (and vice versa) is considered for all slant path angles from vertical to horizontal. Graphical results are presented in full as a resource to be consulted given a particular site and path transmittance prediction requirement.

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1. INTRODUCTION

The Australian Defence Force needs to be able to predict the performance of its electro-optic(E-O) systems throughout the whole Australian environment. The effective use of E-O systems is dependent upon as much knowledge as possible of the effect that the atmosphere intervening between the target and the detector has on the propagation of infrared (IR) radiation.

There are models available for predicting the atmospheric transmittance over a particular path, given appropriate information about the atmosphere along the path. The most notable example is the LOWTRAN computer model(ref.1). Predictions from this model have been compared with measurements in Australian environments and several discrepancies have been reported(refs.2,3,4,5,6). In particular, long path length measurements in the high water vapour content environment of the tropics have highlighted the need to reduce the LOWTRAN self-broadening absorption coefficients considerably(ref.5). It now appears that the LOWTRAN model can be used with some confidence for predictions of visible or IR transmittance in Australian environments. However, this use requires that meteorological parameters appropriate to the Australian environment are supplied. This is not always available and there is often need for recourse to a model atmosphere. LOWTRAN incorporates six standard atmospheric models, but these pertain to the Northern Hemisphere, and are therefore not necessarily applicable to Australian conditions.

The aim of this work is twofold: (i) to investigate the applicability of the standard atmospheric models to the Australian environment; and (ii) to consider the effect of the Australian environment upon the tranmission of IR radiation. The questions addressed are:

(1) What is the relative sensitivity of IR radiation transmittance to various atmospheric parameters?

(2) How does the atmosphere of the Australian environment differ from the standard atmospheric models, and how can these models be used?

(3) How much Australian data must be specified in order to ensure a particular accuracy in the transmittance?

(4) At a particular range, what will be the atmospheric transmittance in various Australian environments?

(5) If a particular atmospheric transmittance is required, what range can be covered in various Australian environments?

These questions are discussed in Sections 3.1 to 3.5 respectively. A few graphical presentations of results are contained within these sections to illustrate general concepts, while the bulk of the results are to be found in appendices at the end of the report. It is hoped that this will provide a convenient reference source for those needing knowledge of the transmission of IR radiation through the Australian atmosphere.

2. BASIS OF CALCULATIONS

2.1 Data

Meteorological data for various Australian environments were obtained from the Bureau of Meteorology(refs.7,8). Four sites were considered: Adelaide, Darwin, Perth and Willis Island. Perth was taken as representative of an Australian temperate environment (Adelaide was very similar) and Darwin was taken as representative of an Australian tropical environment (Willis Island was very similar). The extreme summer and winter (or wet and dry) months were used in detailed analysis. Conditions at other times of the year can be approximated by interpolation.

The data available consisted of pressure, geopotential height, temperature and mixing ratio, at approximately 1.5 km intervals as determined on radiosonde flights at time 2300 GMT (0830 CST and 0700 WST). No information was available on aerosols. Data were averaged over the 10 year period 1970 to 1979 and standard deviations calculated on the daily values. Conversions of the data to the same terms as those used for the standard models were performed as follows:

(i) Conversion of geopotential height to altitude;

The geopotential height is given by(ref.9),

$$H(Z,\phi) = \frac{1}{G}\int_{0}^{Z} g(Z,\phi)\, dZ \;, \qquad (1)$$

where Z = geometric altitude, in geometric metres (m),
H = geopotential altitude, in geopotential metres (m'),
g = acceleration due to gravity,
ϕ = angle of latitude,
G = 9.80665 $m^2 s^{-2} (m')^{-1}$, which implicitly defines one standard geopotential metre.

Assuming an inverse square law for gravitation,

$$g(Z,\phi) = \frac{g_0(\phi)\; R(\phi)^2}{[R(\phi) + Z]^2} \qquad (2)$$

where g_0 = sea level value of acceleration due to gravity

$= 9.806160\,(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi)$ (ref.9)

R = effective earth radius, making allowance for the nonspherical figure of the earth, its mean density distribution and centrifugal acceleration,

$$= \frac{2g_0\,(\phi)}{(3.085462 \times 10^{-6}) + (2.27 \times 10^{-9} \cos 2\phi) - (2 \times 10^{-12} \cos 4\phi)}$$

(ref.10)

this leads to

$$Z(H,\phi) = \frac{R(\phi)\; H(\phi)}{\frac{g(\phi)\; R(\phi)}{G} - H(\phi)} \qquad (3)$$

(ii) Conversion of mixing ratio to water vapour density:

From the definitions of mixing ratio r (ratio of the mass of water vapour present in a particular volume to the mass of dry air present in the same volume(ref.11)), and of water vapour density ρ_w (ratio of the mass of water vapour present in a particular volume to that volume), we have:

$$\rho_w = \left[\frac{r}{1+r}\right]\rho \tag{4}$$

where ρ is the density (the ratio of the total mass in a particular volume to that volume).

The real atmosphere conforms very closely to the equation of hydrostatic equilibrium for a static atmosphere;

$$dP = -\rho g dZ, \qquad \text{(where P = pressure).} \tag{5}$$

(for an atmosphere in motion there are additional terms which are quite negligible in almost all circumstances(ref.12)).

Using equations (2) and (5) the water vapour density expression becomes

$$\rho_w = \left[\frac{-r}{1+r}\right]\frac{[R(\sigma) + Z]^2}{g(\phi)\ R(\phi)^2}\frac{\partial P}{\partial Z} \tag{6}$$

2.2 Model

The computer model LOWTRAN 6(ref.1) is used to calculate the IR atmospheric transmittance. This model can be used to predict the visible or IR transmittance over any path within the earth's atmosphere at moderate spectral resolution (20 cm^{-1}). It uses a single parameter band model for molecular absorption, and includes the effects of continuum absorption, molecular scattering and aerosol extinction. However, aerosol extinction is omitted from this analysis due to the unavailability of appropriate data.

Calculations have been performed for the two atmospheric IR windows, 3 to 5 µm and 8 to 12 µm. The program has been slightly modified in the 8 to 12 µm region to bring the water vapour continuum coefficients into line with more recent laboratory data of Burch et al(ref.13) which confirmed concurrent findings from atmospheric transmission studies(ref.5). These changes are outlined in Appendix VI.

It must be noted that throughout this work it is assumed that the LOWTRAN model accurately predicts the transmittance, given accurate meteorological parameters. However, in reality this model will give rise to an error in the transmittance, independent of that described in this report (Section 3.3). This error, which arises from various assumptions and mathematical approximations, is quoted as being better than 10%(ref.14, p 138). Furthermore, the transmittance values in this report are target-independent and system-independent averages across each waveband, reflecting only the atmospheric transmission; no attempt is made to account for the spectral characteristics of the target or the sensor.

3. PROPAGATION RESULTS

3.1 Sensitivity

This section deals with the relative sensitivity of IR radiation transmittance to the various atmospheric parameters. This would be expected to vary with the type of environment, the actual path and the wavelength band considered. The parameters considered are altitude, temperature and water vapour, as functions of the independent variable pressure. For a measure of the sensitivity we use the change in transmittance corresponding to a change in each parameter by one standard deviation from the mean meteorological value. A typical result is given in figure 1, while figures I.1 and I.2 (given in Appendix I) illustrate the effect for each of the Australian environments and the two wavebands studied. A vertical path from the earth's surface to an altitude of 7 km is taken to represent each situation. The average transmittance (averaged over the whole spectral band using the mean meteorological parameters) as well as the relative change in transmittance for each standard deviation variation accompanies each figure.

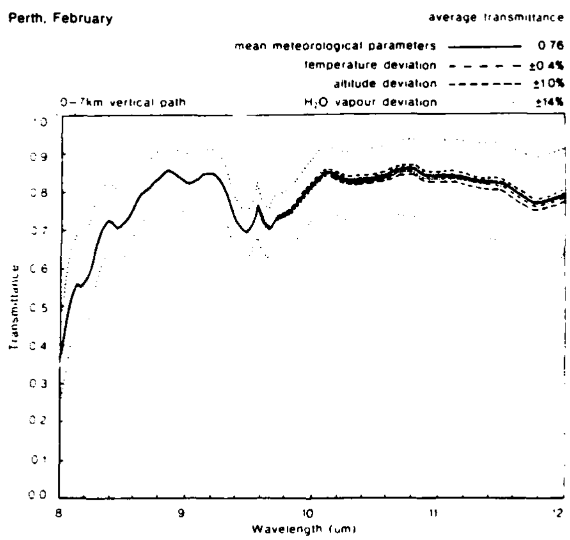

Figure 1. Spectral transmittance for Australian temperate summer environment, in the 8 to 12 μm waveband (0 to 7 km vertical path), showing the sensitivity to various atmospheric parameters (one standard deviation on either side of the mean)

These figures indicate that the IR transmittance is much (well over an order of magnitude) more sensitive to water vapour density than to temperature or altitude in both the 3 to 5 μm and 8 to 12 μm wavelength regions. The sensitivity to temperature and altitude does however increase with wavelength. In the 3 to 5 μm band the sensitivity to altitude is slightly greater than to temperature whereas in the 8 to 12 μm band it is generally the other way around. (It should be noted that no aerosol effects are included). The directions of the sensitivities are such that an increase in water vapour content, a decrease in temperature and an increase in altitude all serve to decrease the transmittance.

This information can be helpful not only in knowing for which parameters it is most important to have accurate measurements, but also to give an idea of how much the transmittance can vary from day to day in a particular environment just due to the likely fluctuation of one of the meteorological parameters.

The diurnal temperature range can be significantly greater than the standard deviation variation about the mean at one particular time of day. This can lead to a transmittance deviation of double the magnitude; however such a variation is still an order of magnitude less than that due to the standard deviation in the water vapour density.

3.2 Australian environment

This section deals with the difference between the atmosphere of the Australian environment and that of the standard atmospheric models, and also the use of these models in Australian situations. Comparisons of the Australian data with the standard model data, in terms of the three parameters pressure, temperature and water vapour density, as functions of altitude are illustrated in Appendix II (figures II.1 to II.3). For each parameter the four standard models, Tropical, Mid-latitude summer, Mid-latitude winter and US Standard (1962) are first compared with each other, and then data for each of the Australian sites and seasons are compared with the models closest to them.

From these graphs it appears that:

(i) the pressure profile is relatively insensitive to the type of environment, there being little change between any of the standard models (figure II.1(a)) or the Australian data (figures II.1(b) to II.1(e)). Nevertheless, within a particular environment the variation in pressure from day to day is so small (as indicated by the small standard deviations about the means - the size of the dots on the graph are larger than the standard deviations) that it is still possible to correlate the data from a particular site with individual standard models. This is summarised in Table 1 where indication is given as to which LOWTRAN model best approximates the Australian data.

TABLE 1. AUSTRALIAN DATA-LOWTRAN MODEL COMPARISON FOR PRESSURE

Australian Environment		Portion of	Closest LOWTRAN	Graph
General	Specific	Profile	Model	Ref.
Temperate, summer	Perth, February	0 to 30 km	tropical	II.1(b)
Temperate, winter	Perth, August	0 to 18 km	US Standard	II.1(c)
		18 to 30 km	tropical	II.1(c)
Tropical, summer	Darwin, January	0 to 22 km	tropical	II.1(d)
		22 to 30 km	US Standard	II.1(d)
Tropical, winter	Darwin, August	0 to 30 km	tropical	II.1(e)

(ii) The <u>temperature</u> profile shows more variation with environment (figure II.2), and hence the models do not fit the Australian data as well as they did for pressure. Nevertheless, at any particular altitude the model that best approximates the Australian environment at that point is generally within two standard deviations of the mean of the local meteorological data. The day-to-day variability in the local temperature values (as indicated by the standard deviations) has also increased, but it is still generally less than the change associated with a change in environment. The models best approximating each Australian environment are outlined in Table 2.

TABLE 2. AUSTRALIAN DATA-LOWTRAN MODEL COMPARISON FOR TEMPERATURE

Australian Environment		Portion of Profile	Closest LOWTRAN Model	Graph Ref.
General	Specific			
Temperate, summer	Perth, February	0 to 3.0 km	mid-latitude summer	II.2(b)
		3.0 to 30.0 km	tropical	II.2(b)
Temperate, winter	Perth, August	0 to 30.0 km	US Standard	II.2(c)
Tropical, summer	Darwin, January	0 to 30.0 km	tropical	II.2(d)
Tropical, winter	Darwin, July	0 to 2.5 km	mid-latitude summer	II.2(e)
		2.5 to 30.0 km	tropical	II.2(e)

(iii) The <u>water vapour density</u> profile shows the largest variation with environment and hence there is less similarity between the Australian data and the models than for the other parameters. Also the variability in the meteorological data from day-to-day (as indicated by the standard deviations) can be so great that the variations can be larger than the difference from one standard model to another, (figure II.3). Hence the choice of a model for extrapolation purposes is not so clear cut as it has been for other parameters. Table 3 outlines the most appropriate models to use under various circumstances.

These correlations between the Australian environment measurements and the standard models can be used directly as a guide in the extrapolation or interpolation of measured data where it is desired to deal with the meteorological parameters as ends in themselves. This may be the case if the specific purpose of formulating the atmospheric profile is yet to be decided - perhaps the transmission path or the wavelength band is not specified, or data may only need to be approximated from a model for one relatively insignificant parameter, in which case it may be simpler to treat the supplementing of data for this parameter as an isolated problem.

TABLE 3. AUSTRALIAN DATA-LOWTRAN MODEL COMPARISON FOR WATER VAPOUR DENSITY

Australian Environment		Portion of Profile	Closest LOWTRAN Model	Graph Ref.
General	Specific			
Temperate, summer	Perth, February	0 to 1.5 km	mid-latitude summer	II.3(b)
		1.5 to 7.5 km	US Standard	II.3(b)
Temperate, winder	Perth, August	0 to 2.0 km	US Standard	II.3(c)
		2.0 to 7.5 km	mid-latitude winter	II.3(c)
Tropical, summer	Darwin, January	0 to 7.5 km	tropical	II.3(d)
Tropical, winter	Darwin, July	0 to 1.5 km	mid-latitude summer	II.3(e)
		1.5 to 6.0 km	US Standard	II.3(e)
		6.0 to 7.5 km	mid-latitude winter	II.3(e)

However, in the more usual case we are considering, ie where it is the IR transmittance in a particular spectral region and over a particular path that interests us, then more accurate predictions can be obtained by considering the actual effect on the IR transmittance of incorporating various models. Not only does this take into account the relative sensitivity of the transmittance to the various parameters (considered in Section 3.1), but also places due emphasis on those regions in the atmospheric profile where absorption is greatest (ie close to the earth's surface).

If no locally measured data are available then model data must be used for the full profile required. If a limited amount of local data are available then this can be extrapolated with standard models to give the required amount of data. The aim is to determine which of the standard models when used to extrapolate locally measured data, gives the closest results to reality for various Australian environments. This is determined by calculating the transmittance arising when it is assumed that only a limited portion of the local mean meteorological data is available and so this is extrapolated with one of the standard models, and then by comparing this with the transmittance for the full profile of local meteorological data. By repeating this for a number of different models, the best one to use for extrapolation can be selected. The extrapolation procedure employed here incorporates a smoothing of the join of local meteorological data to model data such that the first 2 km of the extrapolated values may be altered[1].

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1. *A computer program is available from the author (GAF) to convert radiosonde data to a form suitable for input to LOWTRAN and to extrapolate it with model data.*

The choice of model for extrapolation depends upon the altitude within the profile from where the extrapolation needs to be taken (ie upon the amount of known local meteorological data). There may also be a dependence upon the value to which the extrapolation is required. (This is only significant for short paths near the earths surface, to an altitude of less than 3 km where local data are known to less than 1 km). A graph can be drawn giving the most appropriate model to use given any amount of known local data (or none) and the final altitude to which the calculation is required. The LOWTRAN program has the facility to use a different model for the pressure and temperature profiles as to that used for the water vapour profile, and so this flexibility is allowed in this analysis. The results which follow pertain to IR transmission in the 8 to 12 μm window. However, they differ very little in the 3 to 5 μm window. Figure 2 illustrates a typical result.

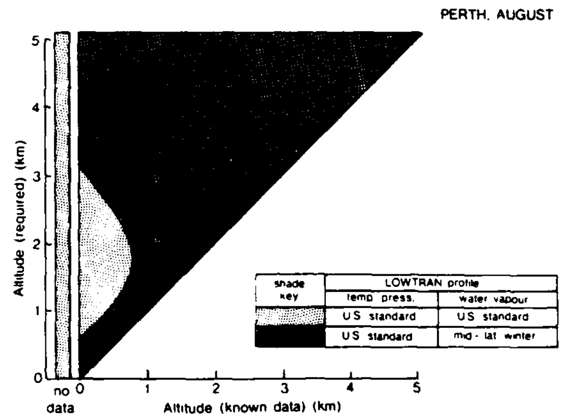

Figure 2. LOWTRAN meteorological model to use for extrapolation, if data is only known to a particular altitude, but is required to a higher altitude. (This case is for a temperate winter environment)

Figure 2 indicates that for a temperate winter environment, if little or no local data is available then the US Standard model is best used (for short paths), but if more data is available or longer paths are required then the mid-latitude winter model for the water vapour density gives better results. The main reason for this can be seen from Table 3 where the most significant parameter (water vapour density) shows these trends. The results for all the Australian environments considered are presented in Appendix II (figure II.4).

In this report, for transmission paths which attain an altitude that exceeds the limit of the radiosonde data available (~7 km for mixing ratio and ~30 km for geopotential height and temperature), the meteorological data is extrapolated in accordance with these figures. If no ozone density data are available (as in our case) then they are approximated from the same model as is used for pressure and temperature extrapolation[2].

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2. *This was chosen because the standard model data given in reference 14 indicates some correlation between the ozone density and the temperature. This is particularly evident for the tropical model where in the 10 to 20 km altitude region, both temperature and ozone density display*

The figures described above have been determined from calculations of transmittance assuming that one end of the transmission path is at the earth's surface. This would be expected to be the case for most applications. However, if this is not the case the recommendations given in the figures would not necessarily be appropriate. The largest discrepancy will occur for the case in which no local data is available at all and the whole amount of data needs to be determined from a model. Calculations have been performed for such a situation; figure 3 illustrates a typical result. The results for the four Australian environments considered are presented in Appendix II (figures II.5).

For other situations, where an air-to-air path is involved but when some data is available, then a comparison of the two preceding sets of figures can be used, or alternatively, recourse can be had to an extrapolation of the individual parameters in themselves, as discussed earlier in this section.

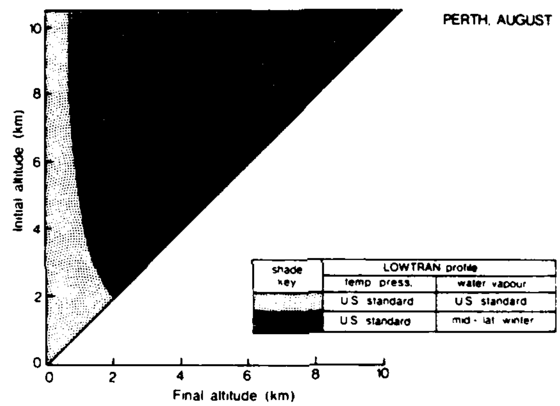

Figure 3. LOWTRAN meteorological model to use for calculations for various atmospheric paths, (if no local data is known). (This case is for a temperate winter environment)

3.3 Accuracy

This section deals with the amount of local meteorological data that must be specified in order to ensure a particular accuracy in the transmittance, and thus with the extent to which data can safely be assumed from the standard atmospheric models. We have seen in the previous section that this will depend very largely upon the particular models used to supplement the local data. In the results of this section the recommended models given in figure II.4 are followed. We use meteorological data which are measured locally up to a particular height and then extrapolated with a standard model. By limiting the local data to various heights it is possible to correlate the accuracy in the transmittance with the height to

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similar non-monotonic features. Furthermore, Strong states "that the absorption by ozone in the IR is proportional to the fourth root of the total pressure"(ref.16).

which data are measured. The analysis concentrates on a path through the whole atmosphere (from the surface to space = 100 km), but treats slant paths as well as vertical paths. As an example, figure 4 is presented below.

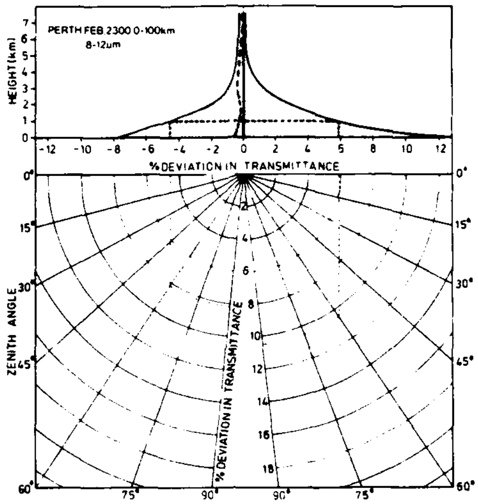

Figure 4. Percent deviation in transmittance as a function of height to which local meteorological data is measured. Mean meteorological data (- - - -). Standard deviations about the mean (———). The polar portion is used to determine the deviation for slant paths. (This case is for a temperate summer environment)

The transmittance accuracy is expressed as a % deviation from the transmittance that would have been predicted had the complete local meteorological profiles been accurately known. Curves are drawn corresponding to the mean values of the meteorological parameters (dashed line), as well as one standard deviation of the independent parameters[3] on either side of the mean (solid lines). Thus for data measured to a particular height, it would be expected that the % deviation in the transmittance would fall somewhere in the shaded region between the two solid lines. If no data is measured then the deviation is generally significantly greater than for the case when even only the ground level values are known, and so is not shown in figure 4, being off scale. The

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3. *Altitude, temperature and water vapour density are taken as independent parameters, pressure being regarded as the fixed parameter. The positive deviation branch corresponds to negative standard deviations for geopotential height and mixing ratio and a positive standard deviation for temperature. It is realised that on rare occasions this may be unrealistic in that it would correspond to a relative humidity of greater than 100%. However, with one parameter (water vapour density) dominating the others, the effect upon the transmittance is very small.*

curves on the upper (linear) portion of figure 4 represent the case for a vertical transmission path. In order to determine the deviation for slant paths (inclined to the vertical) a perpendicular line is dropped from this curve beyond the horizontal axis to the radial line corresponding to the angle of the path (as measured at the earth's surface). The radial distance to this intersection is the % deviation in transmittance for the slant path. Hence, for example (as shown by the dotted line), if meteorological height profile data is measured to only 1 km during summer in a temperate environment, and this data is extrapolated using the model as suggested in Section 3.2, then it would be expected that the predicted transmittance of 8 to 12 μm radiation would be within the range -4.6% to +5.8% of the actual transmittance for a vertical path to space. For a slant path at 60° from the vertical (zenith angle) the corresponding range would be -8.2% to +10.5%. Conversely, if a particular accuracy is required in the transmittance, then this graph can be used to indicate the level to which atmospheric data must be measured in the field. Results for the four Australian environments and both atmospheric windows are presented in Appendix III (figures III.1 and III.2).

The shape of the shaded region in these figures is very dependent on the particular models used for extrapolation, (in particular, the position of the dashed line relative to the vertical axis reflects the overestimation or underestimation of the local data by the models).

The size of the shaded region is an indication of the likely error in the transmittance. It is interesting that this is sometimes greater for the 3 to 5 μm region (eg temperate winter environment vertical path, and slant paths in most Australian environments) and sometimes greater for the 8 to 12 μm region (eg tropical environment, wet season, vertical path). This can be thought of in terms of 8 to 12 μm radiation being more sensitive to a change in the water vapour content if the total water content in the path is high, and 3 to 5 μm radiation being more sensitive to a change if the total water content is relatively low.

The effect upon the transmittance deviations of changing the angle of the slant path is greater for the 8 to 12 μm region for all environments considered, however as the water vapour content increases, the difference in sensitivity between the two wavebands decreases.

3.4 Transmittance

This section deals with the atmospheric transmittance that can be expected at various particular ranges. It provides an indication of acceptable emission levels in order to avoid detection at a particular range and of required sensitivity levels in order to ensure detection at a particular range. The transmittance will vary quite markedly with elevation angle, the transmittance being greatest for vertical paths and least for horizontal paths, and it is of interest to know how the transmittance varies with this angle.

The predictions that the LOWTRAN model makes for the Australian environments are presented in polar plots which give a visual representation of how the IR radiation will propagate in all directions. The typical example shown below (figure 5) clearly indicates the reduction in transmittance with range and the significance of the angle of the path, especially for the larger ranges. If aerosol attenuation is included these effects are even more pronounced. Curves (dashed lines) are drawn corresponding to ranges of 1, 3 and 30 km (except where the degree of overlap would be confusing, in which case the 3 km range is omitted). Each of these curves are broadened into regions by taking into account the spread in meteorological data for each environment as indicated by the standard deviations. The results for both wavebands and the four Australian environments considered are presented in Appendix IV (figures IV.1 and IV.2).

As expected from the relative amounts of water vapour present in the different environments considered, the transmittances predicted at particular ranges are lower in summer than in winter and also in tropical as opposed to temperate environments. The combination of these factors results in the tropical dry season environment being similar to the temperate summer environment. It is observed that, except for long ranges through the part of the atmosphere very close to the earth's surface (very large zenith angles), the transmittance of 8 to 12 μm radiation exceeds that of 3 to 5 μm radiation at any particular range. However, the uncertainties in the transmittance are also larger for the 8 to 12 μm radiation.

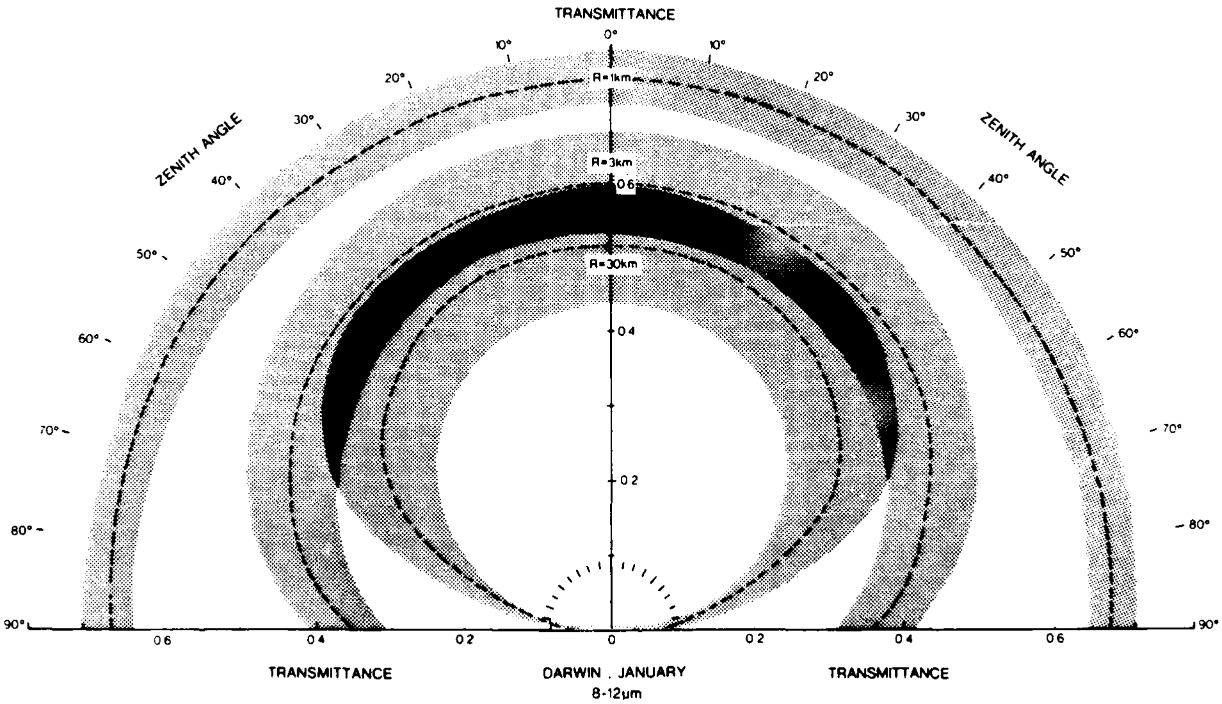

Figure 5. The transmittance at particular ranges. (This case is for a tropical wet season environment)

3.5 Range

This section deals with the range that can be covered if a particular transmittance is required. It provides an indication of how close one needs to be in order to get a particular transmittance (perhaps to ensure detection) and of how far away one needs to be for the transmittance to have dropped below a particular level (perhaps to escape detection). This is determined not only for horizontal and vertical paths but, for paths of all angles through the atmosphere.

The predictions that the LOWTRAN model makes for the Australian environments are presented in logarithmic polar plots which give a visual representation of how far the IR radiation will propagate in all directions. An example is given below (figure 6). Curves (dashed lines) are drawn corresponding to transmittance figures of 0.4, 0.6 and 0.8

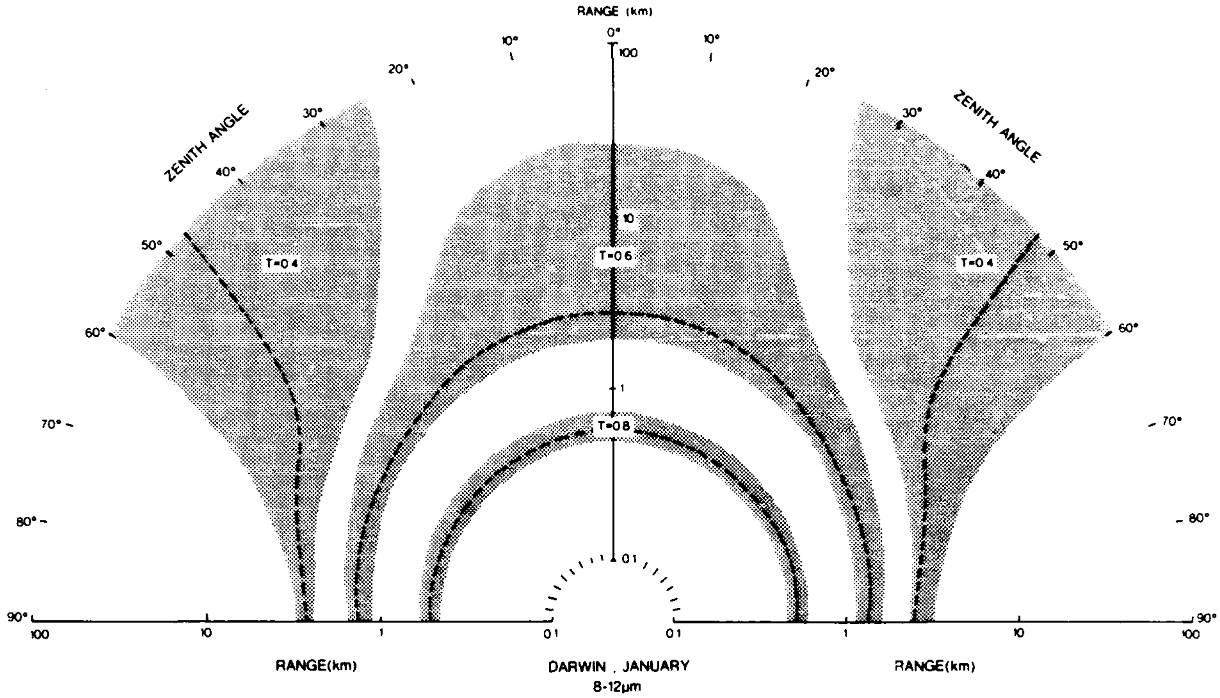

Figure 6. The range covered to give a particular transmittance. (This case is for a tropical wet season environment)

(except where the degree of overlap would be confusing in which case the 0.6 transmittance is omitted). Each of these curves are broadened into regions by taking into account the standard deviations in the various meteorological parameters. Figure 6 clearly indicates the increasing uncertainty in the range as the transmittance falls off for all paths except those constrained to the lowest levels of the atmosphere. If we consider, for example the propagation of 8 to 12 μm IR radiation at a zenith angle of 45° in the environment of figure 6, then we see that the atmospheric transmittance has reduced to 0.8 after about 450 to 650 m propagation. Somewhere between 1.8 and 3.2 km it has reduced to 0.6 and beyond 5 km it is around 0.4. Thus there is a possibility that the atmosphere will allow propagation of this radiation in this direction with a transmittance figure of >0.4 virtually indefinitely, ie right out to space. If transmittance must be above some particular threshold value, then this can be assumed to be the case only for ranges inside of the inner boundary of the region corresponding to that transmittance. If an estimate of the range is required for a particular transmittance value then the dashed line will give the mean value. If transmittance must fall below a particular threshold then this can only be assumed to be the case for ranges greater than that of the outer boundary for the appropriate region. The results for both atmospheric windows and the four Australian environments considered are presented in Appendix V (figures V.1 and V.2).

Again, as expected from the relative amounts of water vapour present, the ranges covered are less in summer than in winter and less in tropical than in temperate environments with the tropical dry season case being similar to the temperate summer case. It is observed that the ranges predicted to give particular transmittances (ie 0.4, 0.6 and 0.8) are greater for 8 to 12 μm radiation than for 3 to 5 μm.[4] However, the uncertainties in the range predictions are also much greater. Hence there may need to be a trade-off between magnitude of range and precise prediction of range in choosing between the two windows.

4. CONCLUSIONS

The most significant factor affecting transmission of IR radiation in Australian environments is the amount of water vapour in the atmosphere, the transmittance being an order of magnitude more sensitive to water content than to temperature or pressure in both atmospheric windows (3 to 5 μm and 8 to 12 μm).

The atmospheric models embodied in LOWTRAN come reasonably close to the 10 year mean measured values (at worst within two standard deviations, and for the most significant parameter water vapour within one standard deviation), but they can still fail quite badly to represent the Australian environment. This is because of the variability inherent in our environment on a day-to-day basis (the model may be within a standard deviation but the standard deviation in the water vapour content is large, and hence the error can be quite large).

Hence if any water vapour content values can be measured locally at run-time, this will greatly enhance the LOWTRAN transmittance prediction capability. In relation to the question of how much data to measure, data measured up to an altitude somewhere between 2 km and 4 km are likely to be sufficient, considering the approximations and assumptions inherent in LOWTRAN (even for paths out to space). If real-time data is unavailable, historical data for the particular site of interest would still be valuable; even if only a ground level value can be specified it will significantly enhance the accuracy of the predictions. Measurements of the temperature or pressure profile would not yield much improvement to the predictions without water vapour data, and so these can adequately be approximated by one of the standard models.

Transmission is worst in the wettest environment (tropical wet season) and best in the driest (temperate winter), with tropical dry season values being very close to temperate summer values (again because of the correspondence of the water vapour contents).

For slant paths (other than those of long-range, near horizontal, very close to the earth's surface) the transmittance is greater in the 8 to 12 μm band than in the 3 to 5 μm band, and hence the former would generally be favoured. However, variability in the meteorological data gives rise to a greater uncertainty in the transmittance in the 8 to 12 μm band. Hence if precision of prediction is more important than a high value for the transmittance, and if meteorological data is having to be approximated from a model, then the 3 to 5 μm band may be more favourable.

5. ACKNOWLEDGEMENT

The perceptive comments of Mr Gavin McQuistan upon this report are much appreciated. Thanks are also due to the staff of Drafting and Graphic Services Group for their work in preparing this report for publication, and especially to Lesley Bray and Des Osborn for their work in producing the figures.

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4. *For much lower transmittances the 3 to 5 μm radiation can cover a longer range than the 8 to 12 μm radiation.*

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16	Strong, J.	J. Franklin Inst. 231, 121 as quoted by reference 10 (1941)

APPENDIX I

FIGURES RELATING TO SECTION 3.1 (SENSITIVITY)

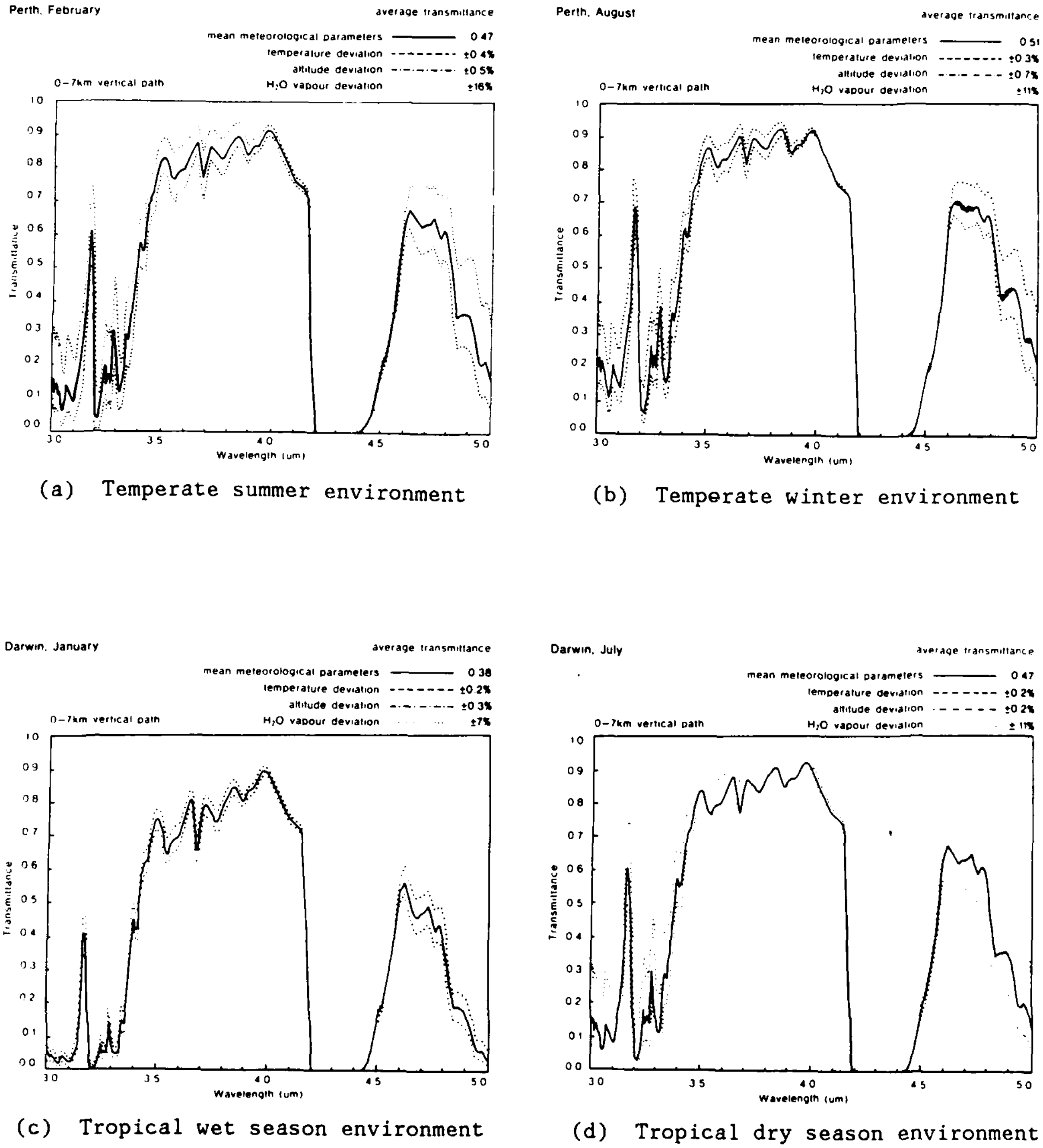
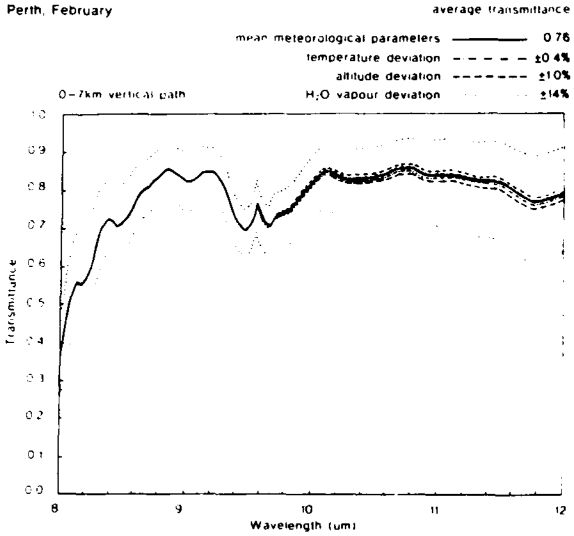
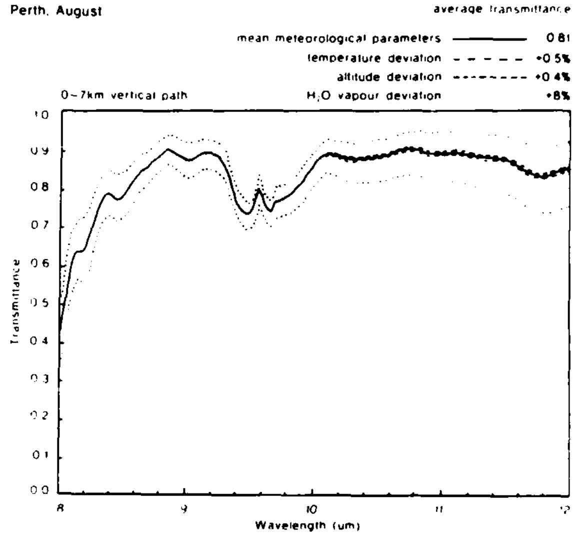


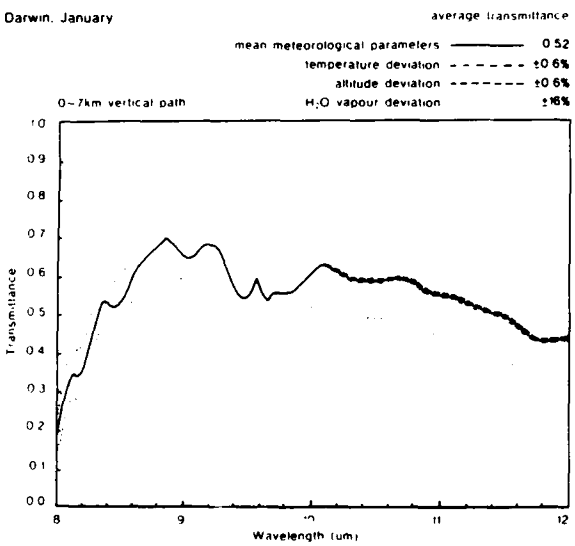
Figure I.1 Spectral transmittance in 3 to 5 μm region for variations in atmospheric parameters



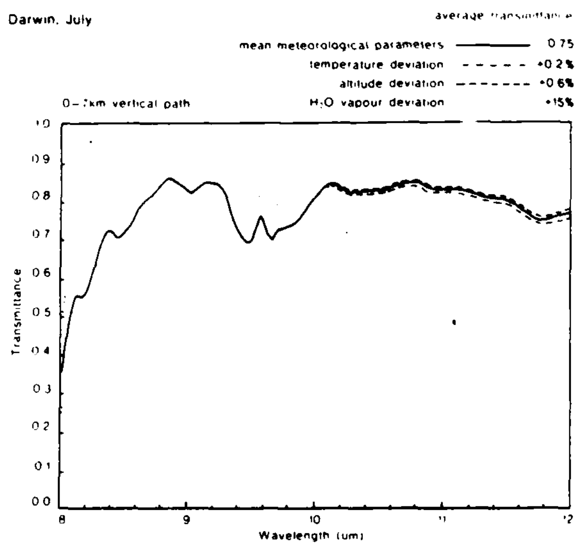
(a) Temperate summer environment



(b) Temperate winter environment



(c) Tropical wet season environment

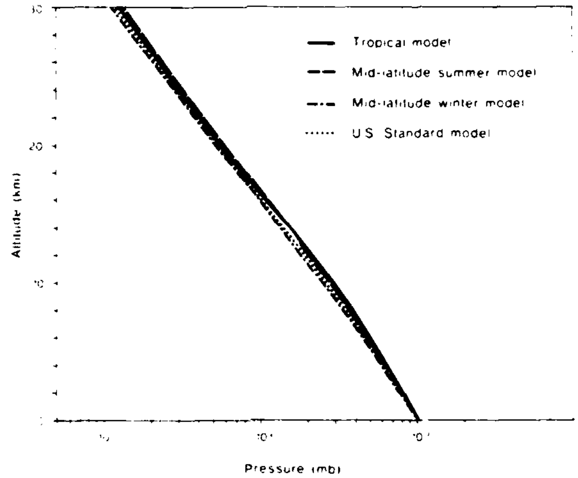


(d) Tropical dry season environment

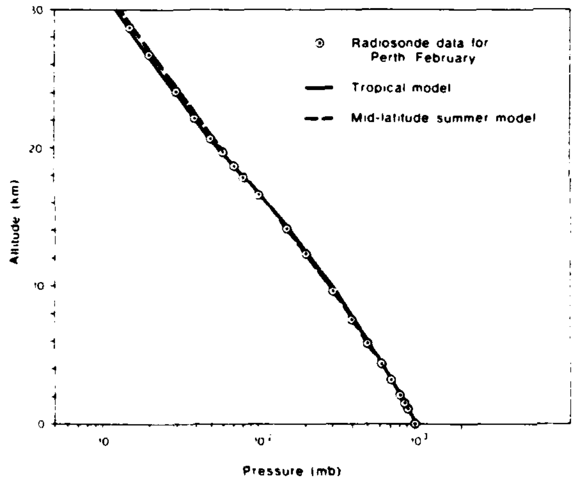
Figure I.2 Spectral transmittance in 8 to 12 μm region for variations in atmospheric parameters

APPENDIX II

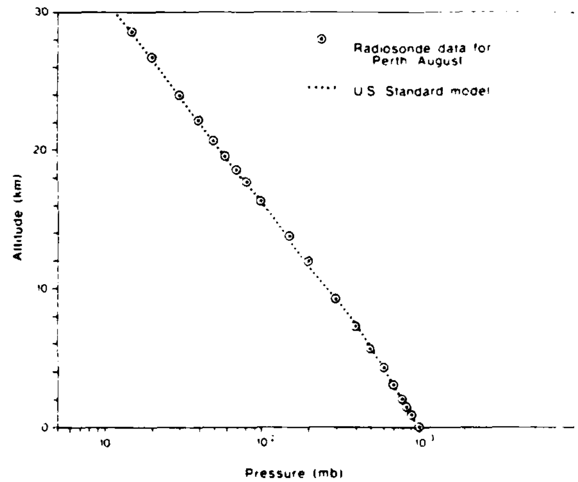
FIGURES RELATING TO SECTION 3.2 (AUSTRALIAN ENVIRONMENT)



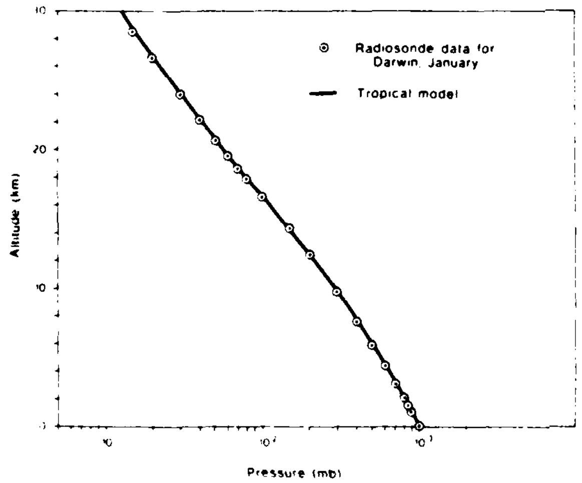
(a) Standard LOWTRAN models



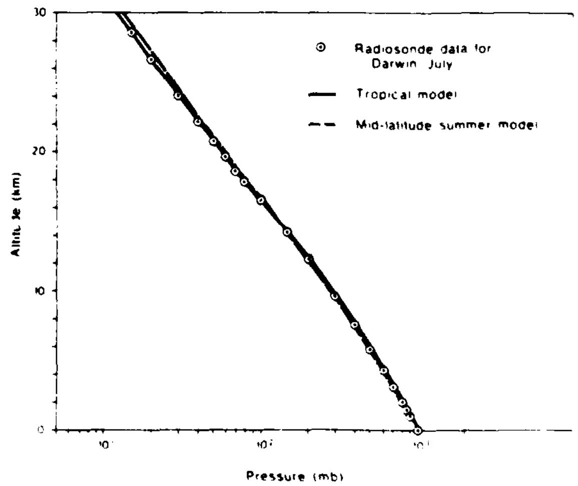
(b) Temperate summer environment



(c) Temperate winter environment

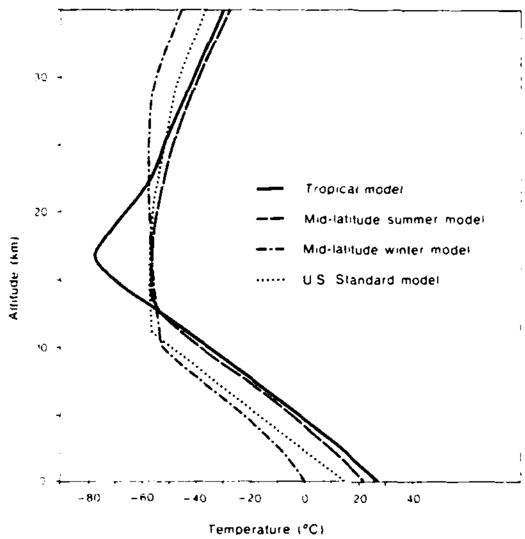


(d) Tropical wet season environment

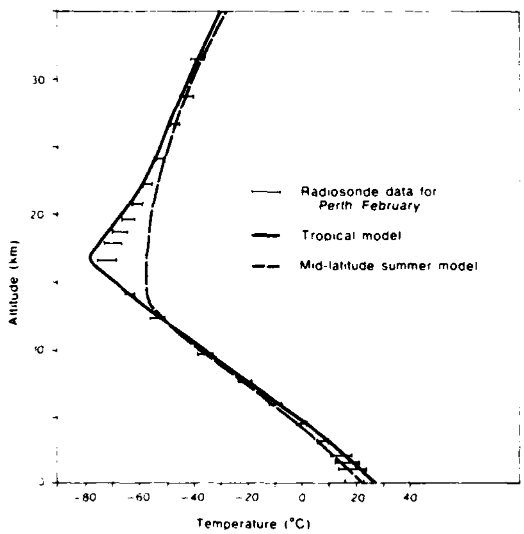


(e) Tropical dry season environment

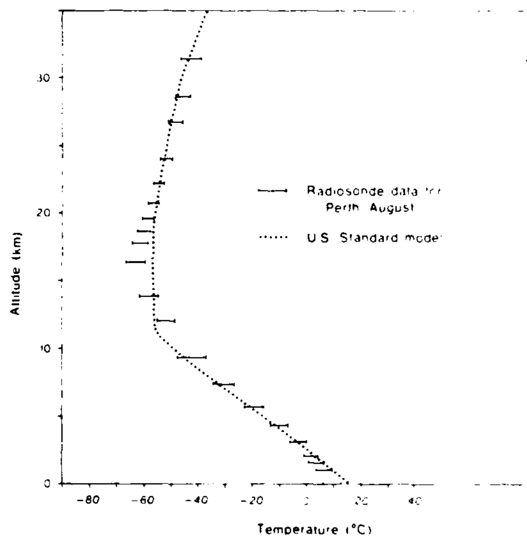
Figure II.1 Pressure profiles (comparison of Australian data with model data)



(a) Standard LOWTRAN models



(b) Temperate summer environment



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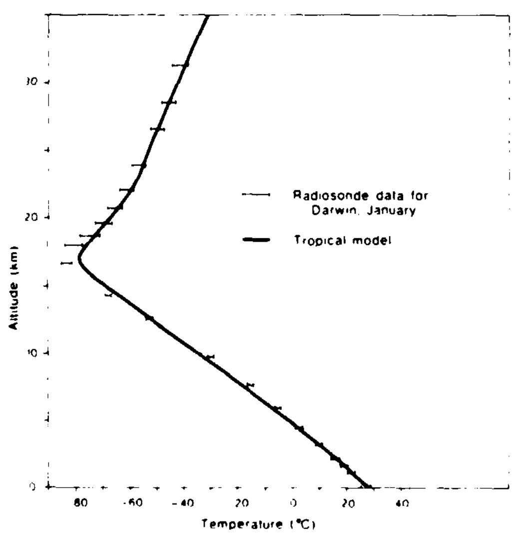
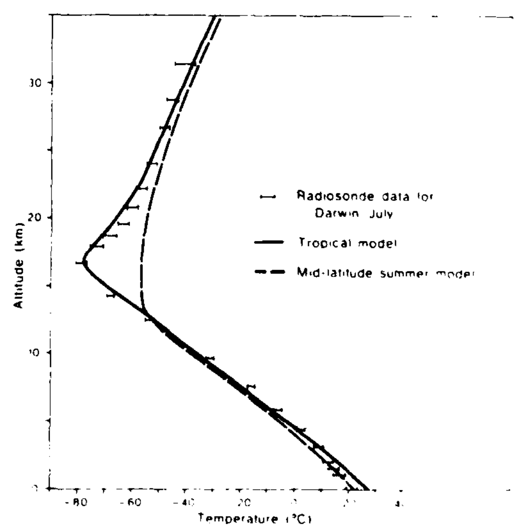
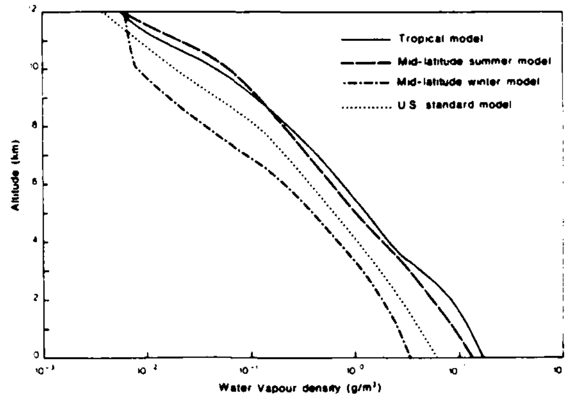


(d) Tropical wet season environment

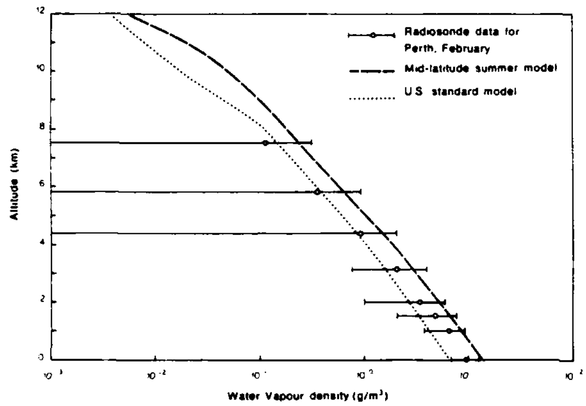


(e) Tropical dry season environment

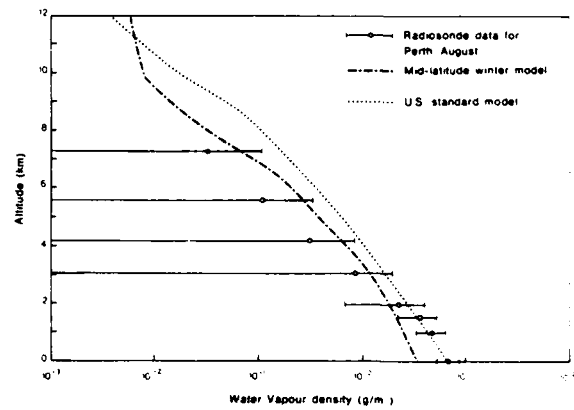
Figure II.2 Temperature profiles (comparison of Australian data with model data)



(a) Standard LOWTRAN models



(b) Temperate summer environment



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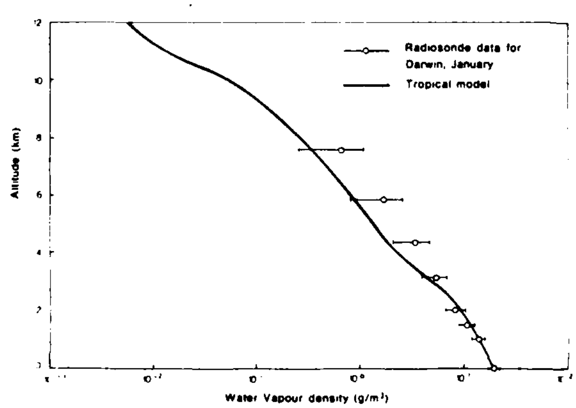
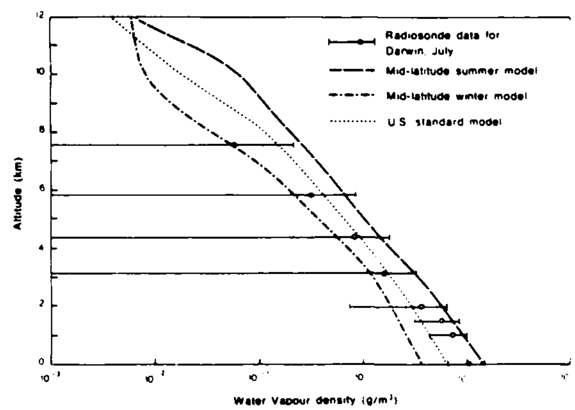
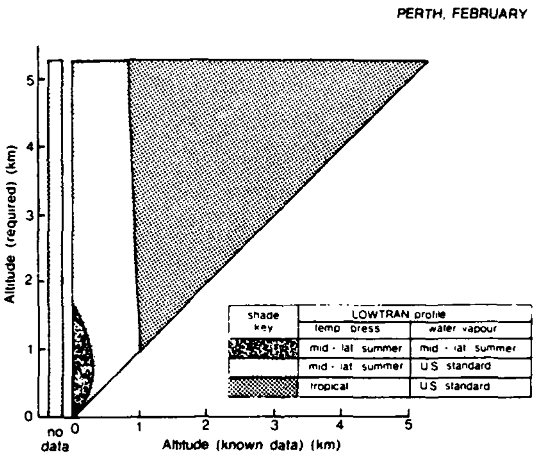


(d) Tropical wet season environment

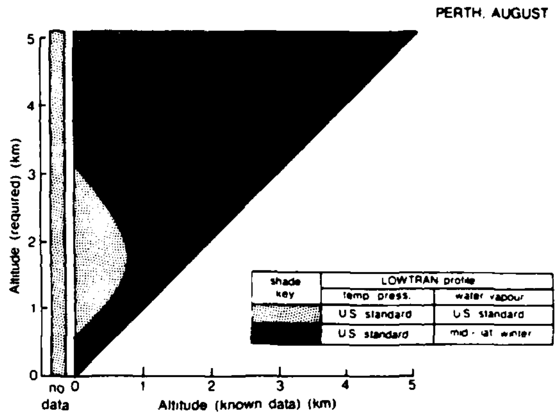


(e) Tropical dry season environment

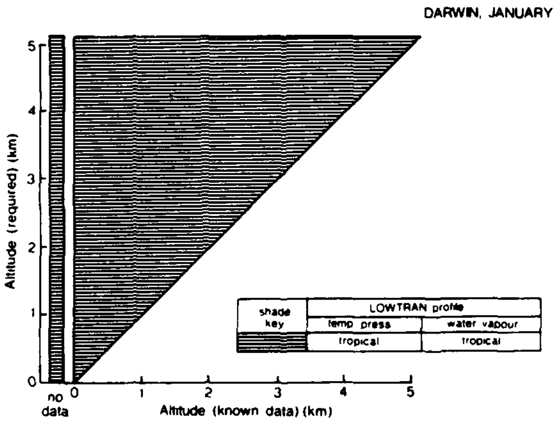
Figure II.3 Water vapour density profiles (comparison of Australian data with model data)



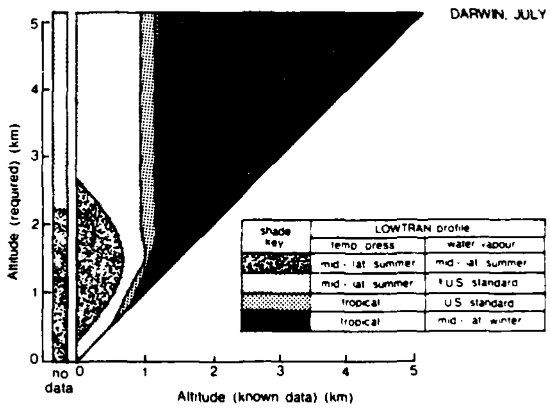
(a) Temperate summer environment



(b) Temperate winter environment

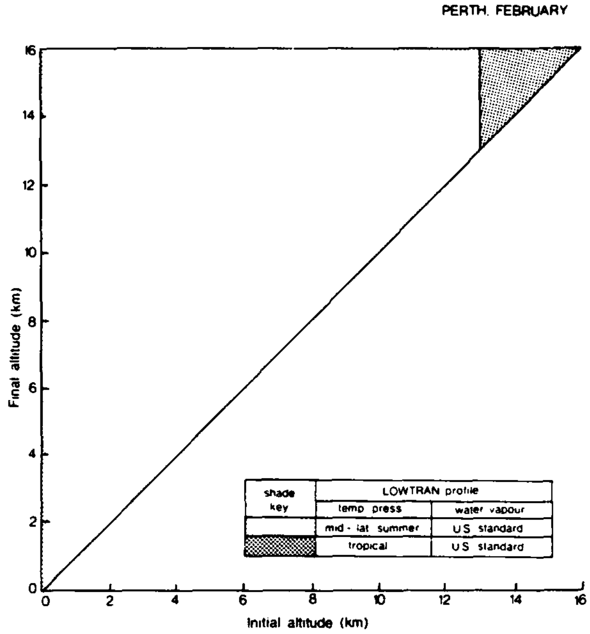


(c) Tropical wet season environment

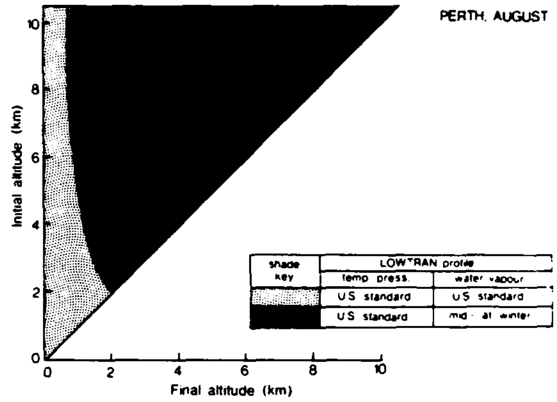


(d) Tropical dry season environment

Figure II.4 LOWTRAN meteorological model to use for extrapolation of paths from the surface, if data is only known to a particular altitude, but is required to a higher altitude



(a) Temperate summer environment



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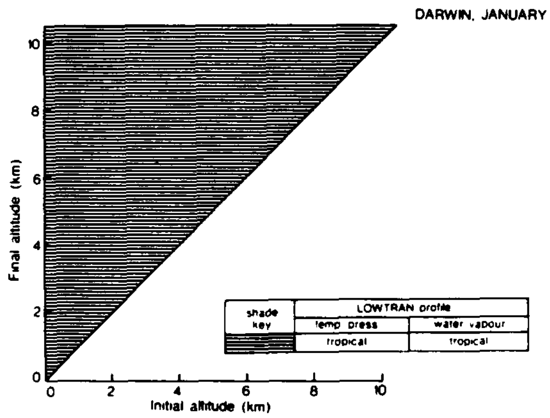
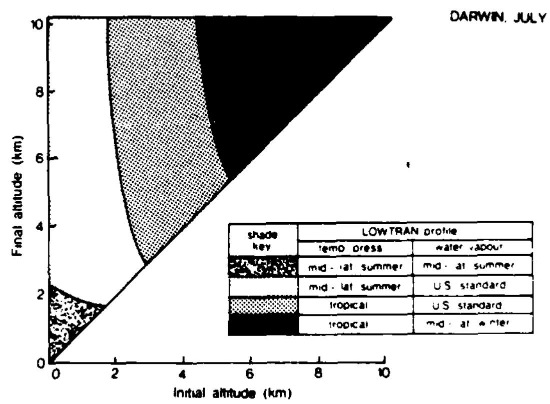


(c) Tropical wet season environment

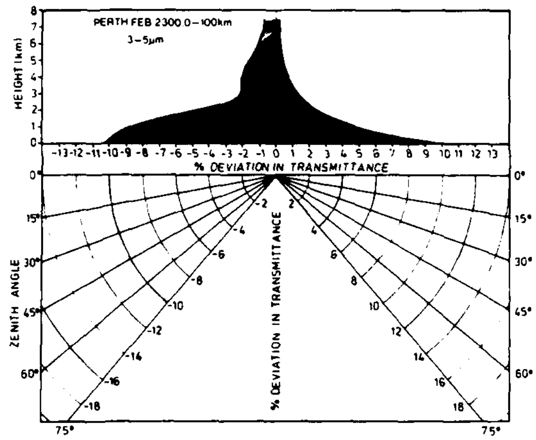


(d) Tropical dry season environment

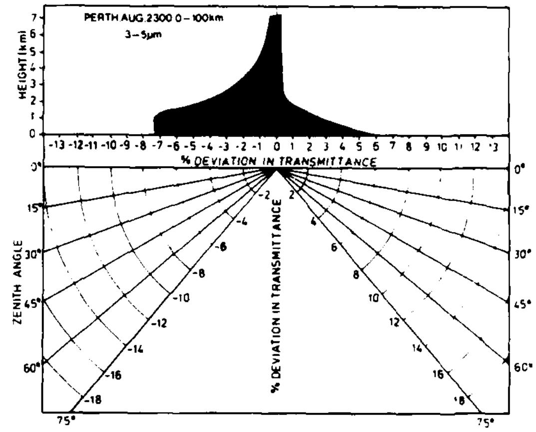
Figure II.5 LOWTRAN meteorological model to use for calculations for various atmospheric paths (if no local data is known)

APPENDIX III

FIGURES RELATING TO SECTION 3.3 (ACCURACY)



(a) Temperate summer environment



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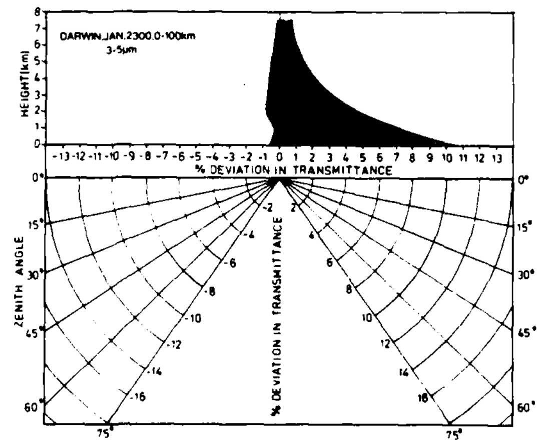
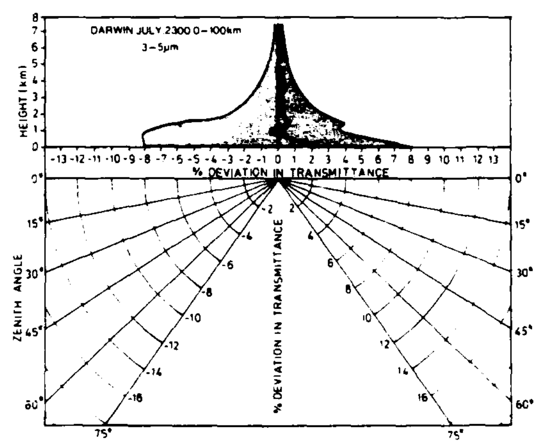
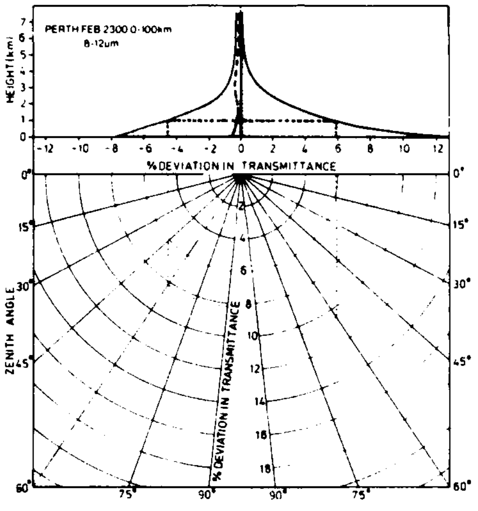


(c) Tropical wet season environment

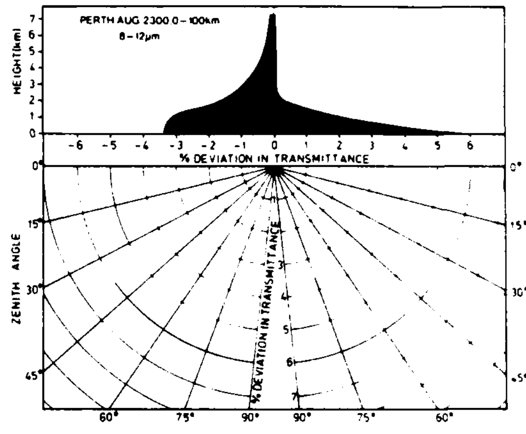


(d) Tropical dry season environment

Figure III.1 Inaccuracy in transmittance due to local meteorological parameters being known only to a particular height, (3 to 5 µm); mean meteorological data (- - - -), standard deviation about the mean (——). The polar portion is used to determine the deviation for slant paths



(a) Temperate summer environment



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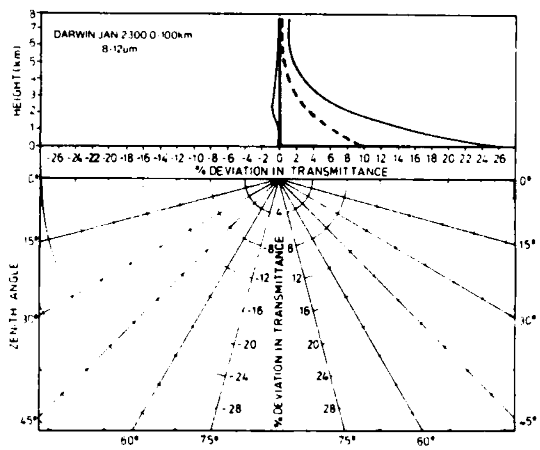
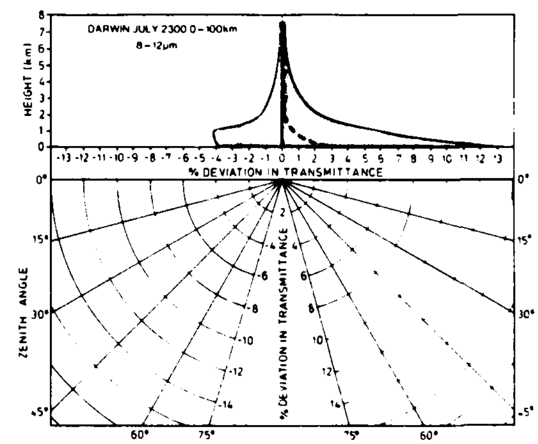


(c) Tropical wet season environment

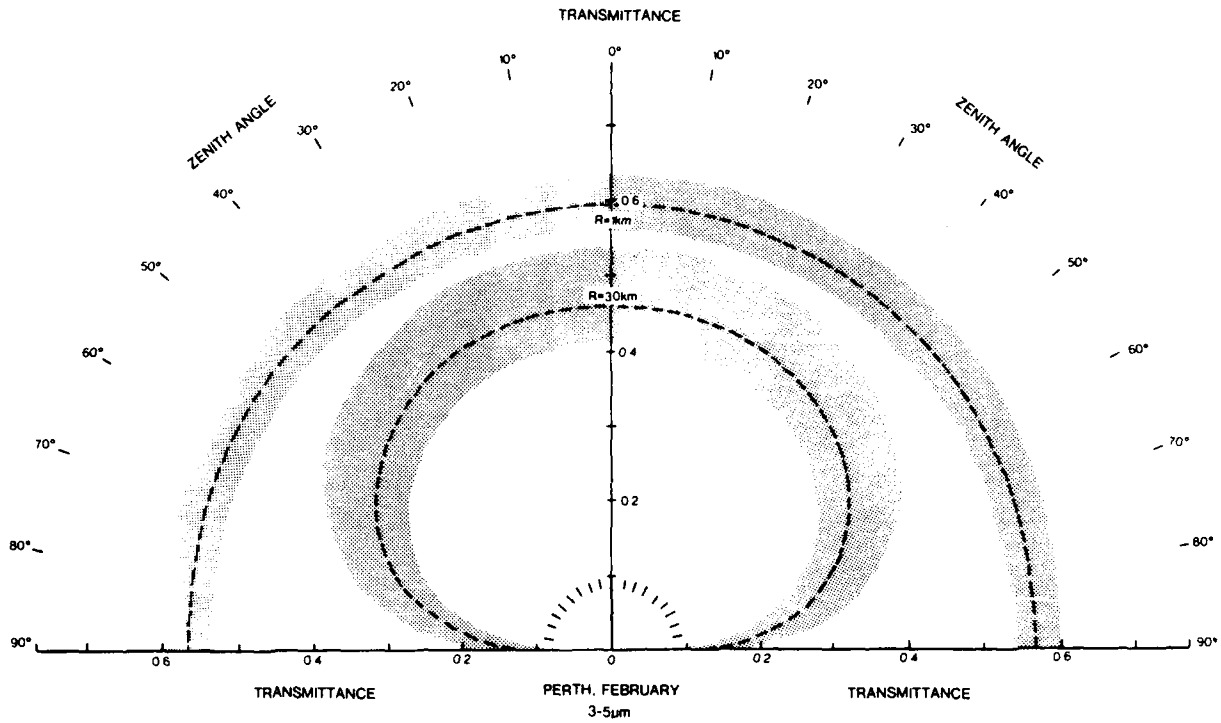


(d) Tropical dry season environment

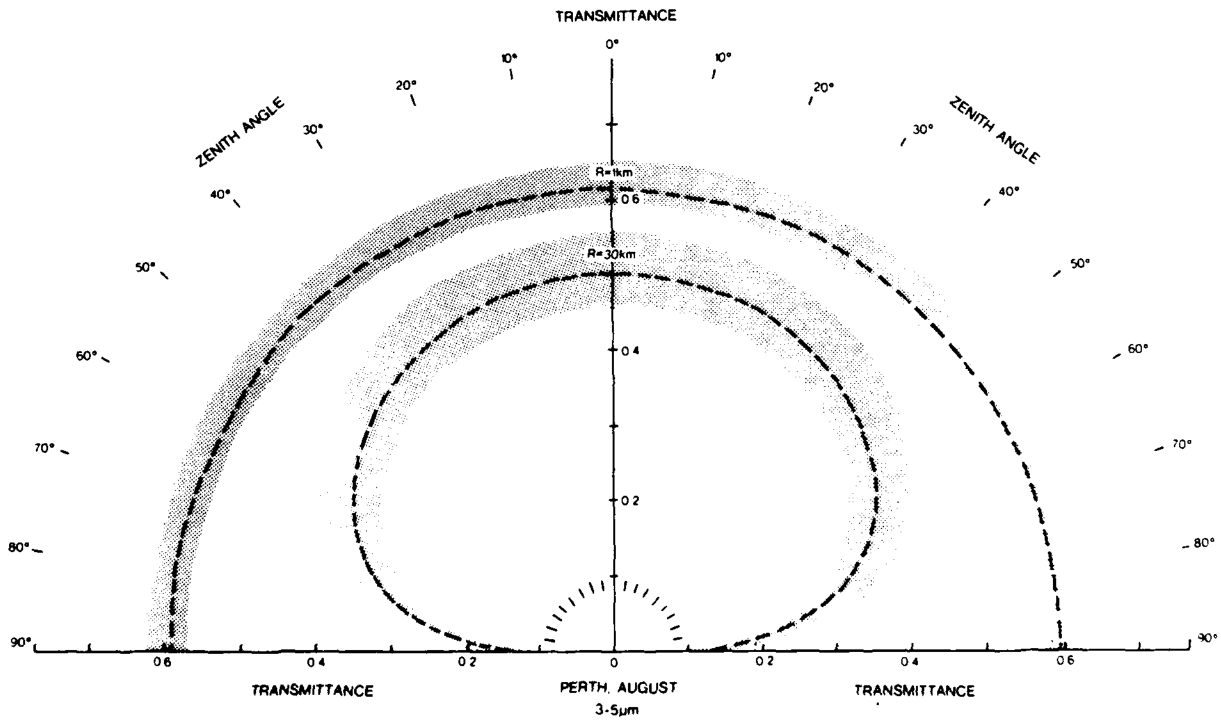
Figure III.2 Inaccuracy in transmittance due to local meteorological parameters being known only to a particular height, (8 to 12 μm); mean meteorological data (- - - -), standard deviation about the mean (——). The polar portion is used to determine the deviation for slant paths

APPENDIX IV

FIGURES RELATING TO SECTION 3.4 (TRANSMITTANCE)

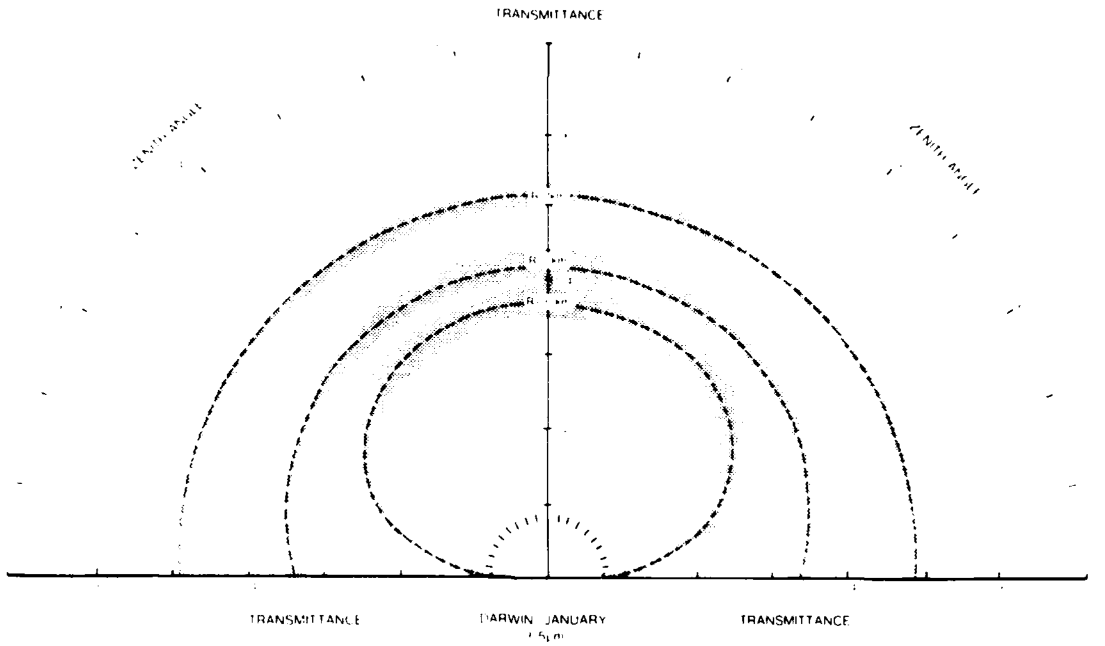


(a) Temperate summer environment

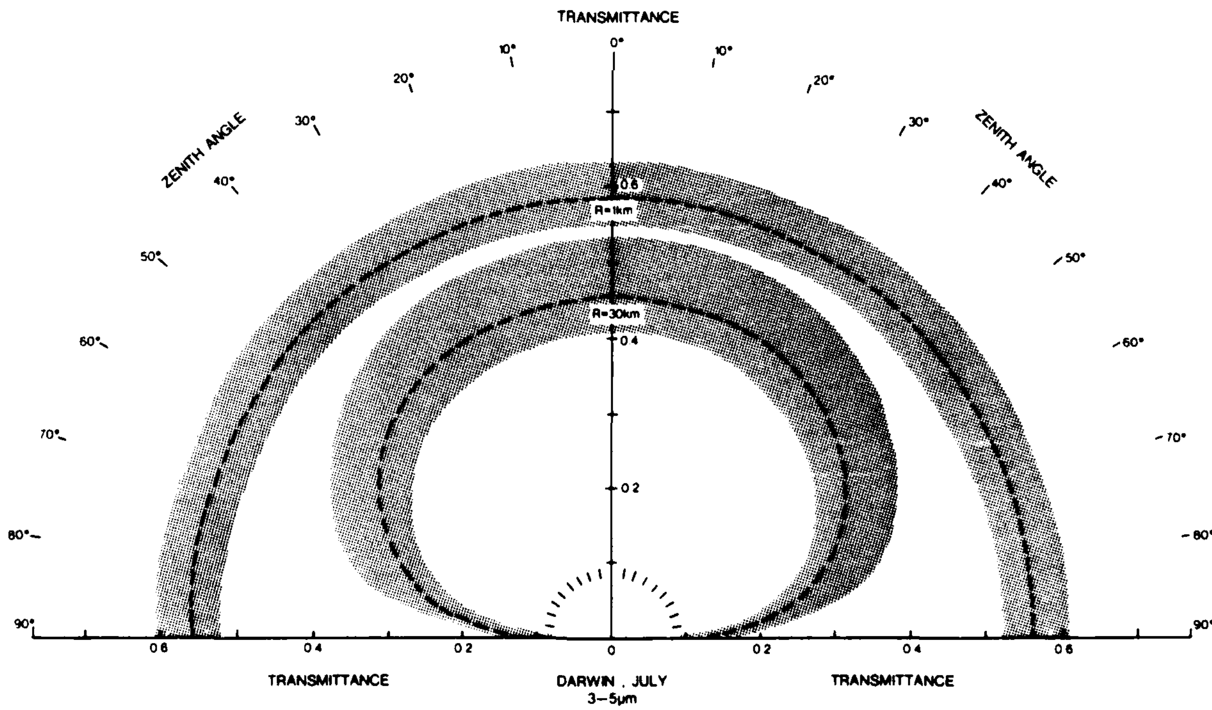


(b) Temperate winter environment

Figure IV.1 The transmittance at particular ranges (3 to 5 μm), mean meteorological data (----), standard deviation about the mean (shaded)

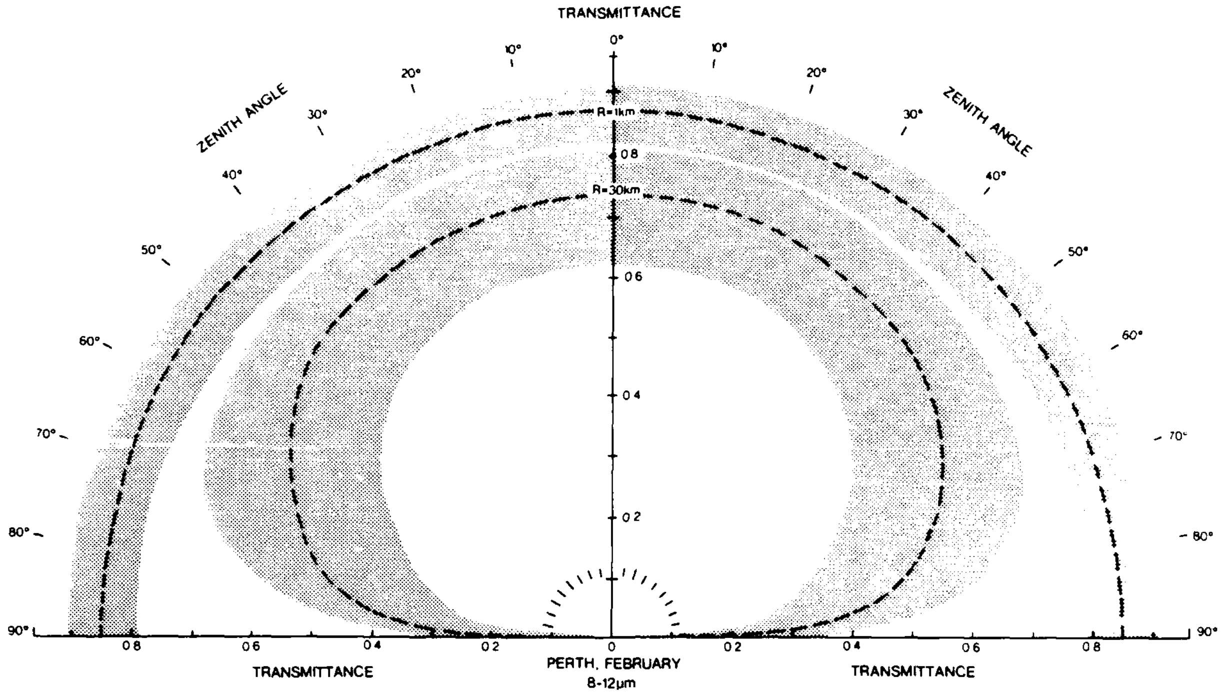


(c) Tropical Wet season environment

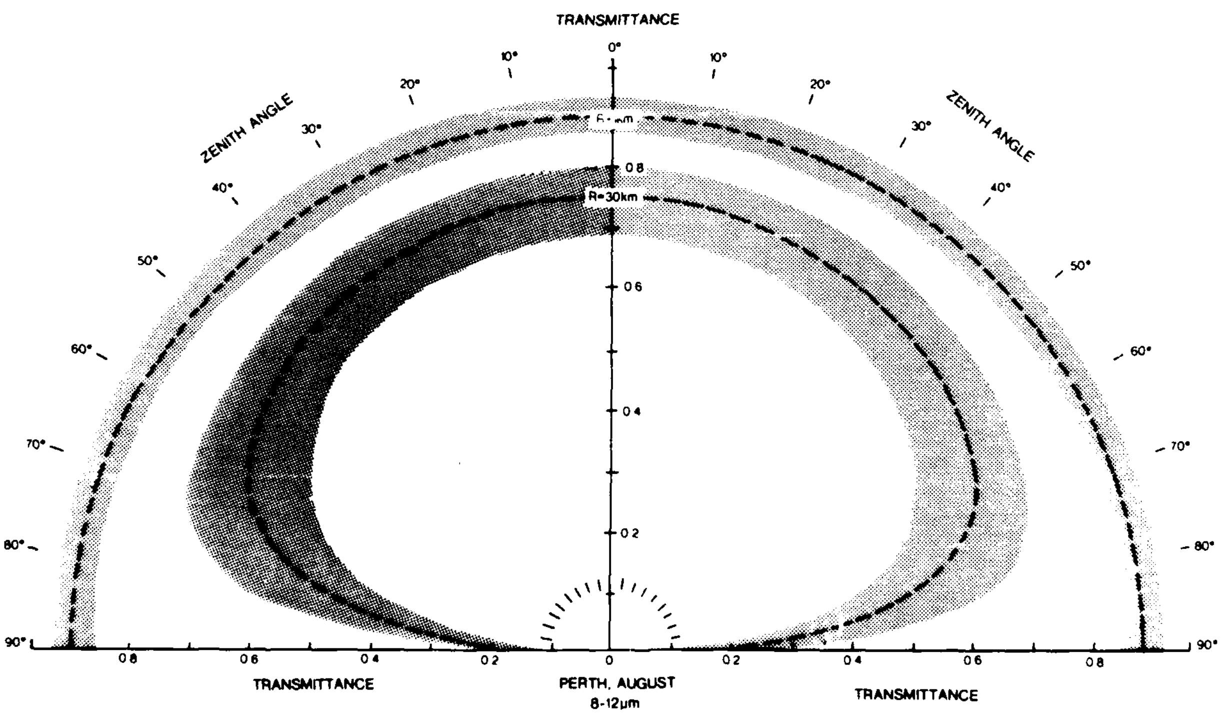


(d) Tropical Dry season environment

Figure IV.1(Contd.).

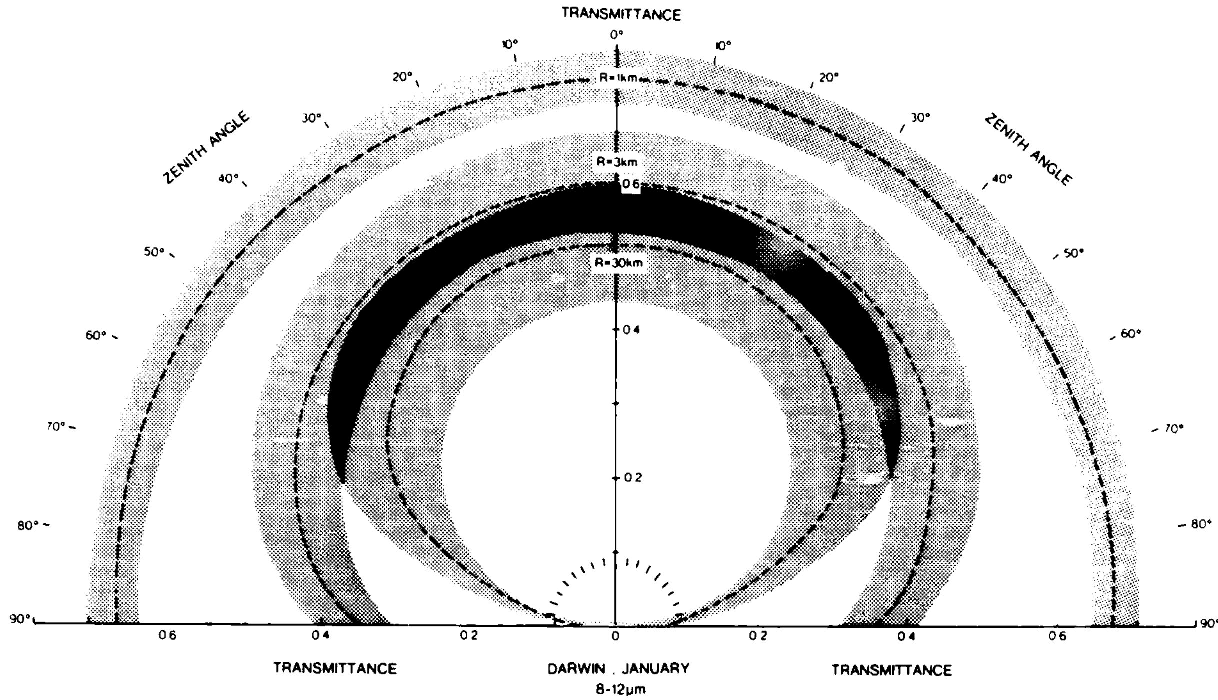


(a) Temperate Summer environment

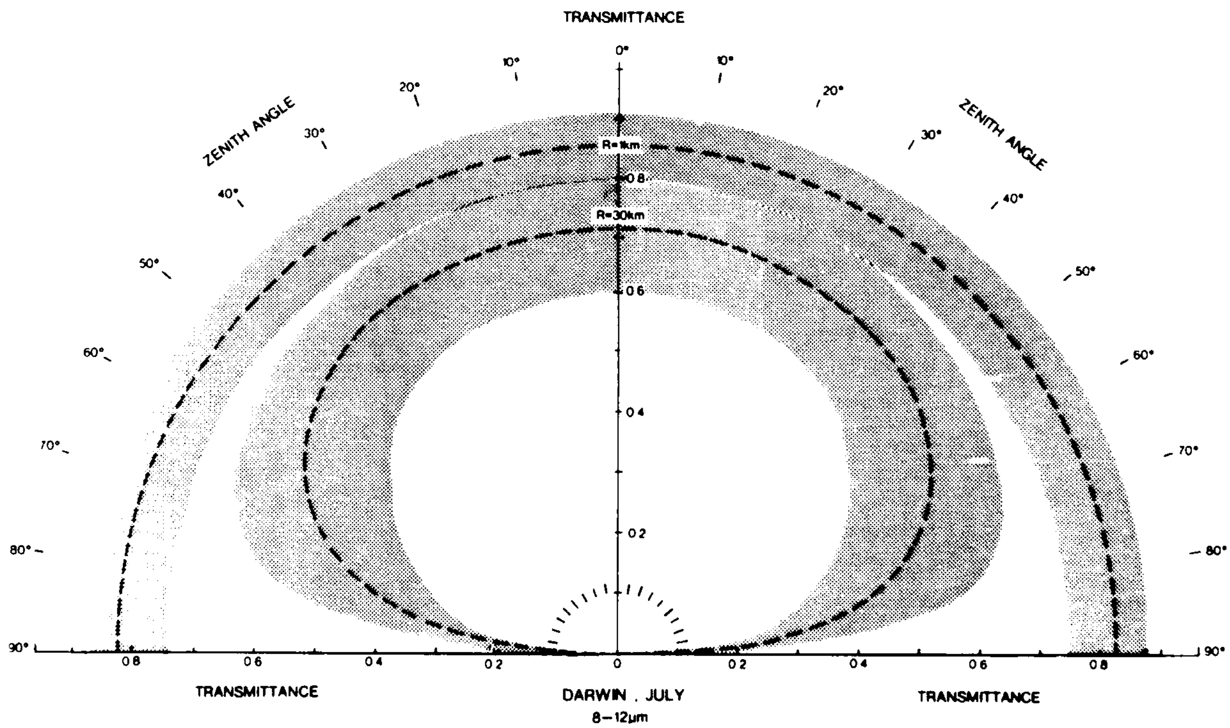


(b) Temperate Winter environment

Figure IV.2 The transmittance at particular ranges (8 to 12 μm), mean meteorological data (- - - -), standard deviation about the mean (shaded)



(c) Tropical Wet season environment

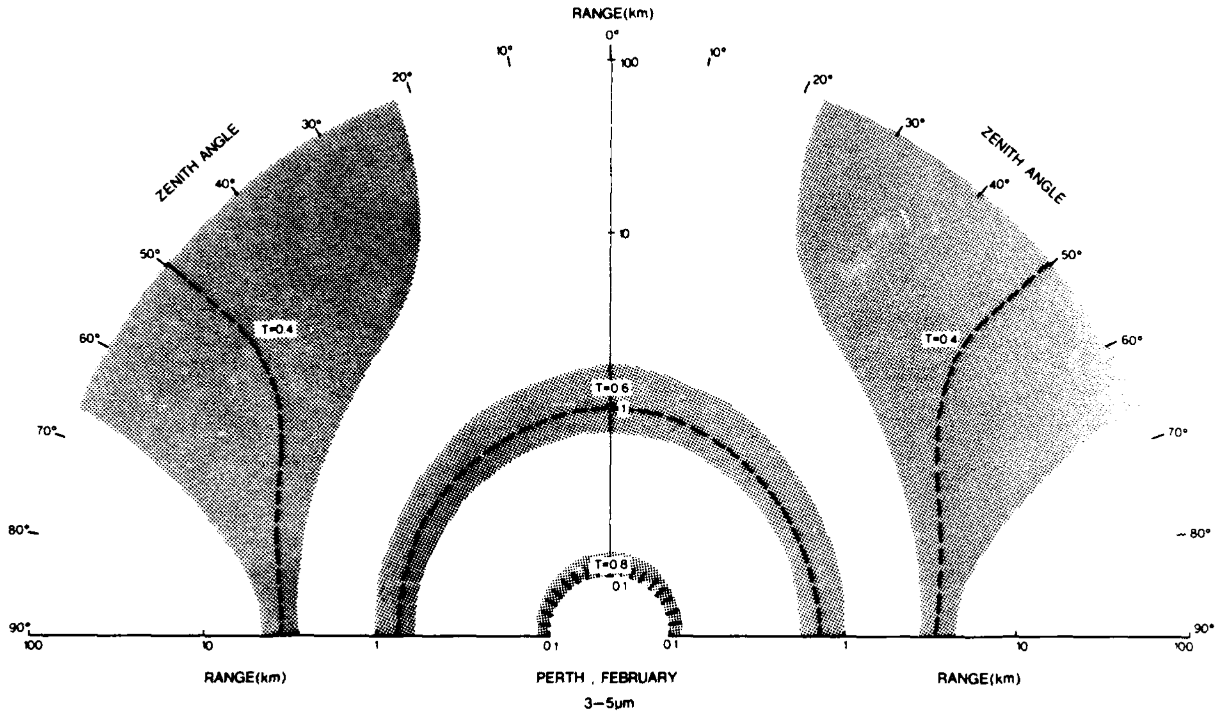


(d) Tropical Dry season environment

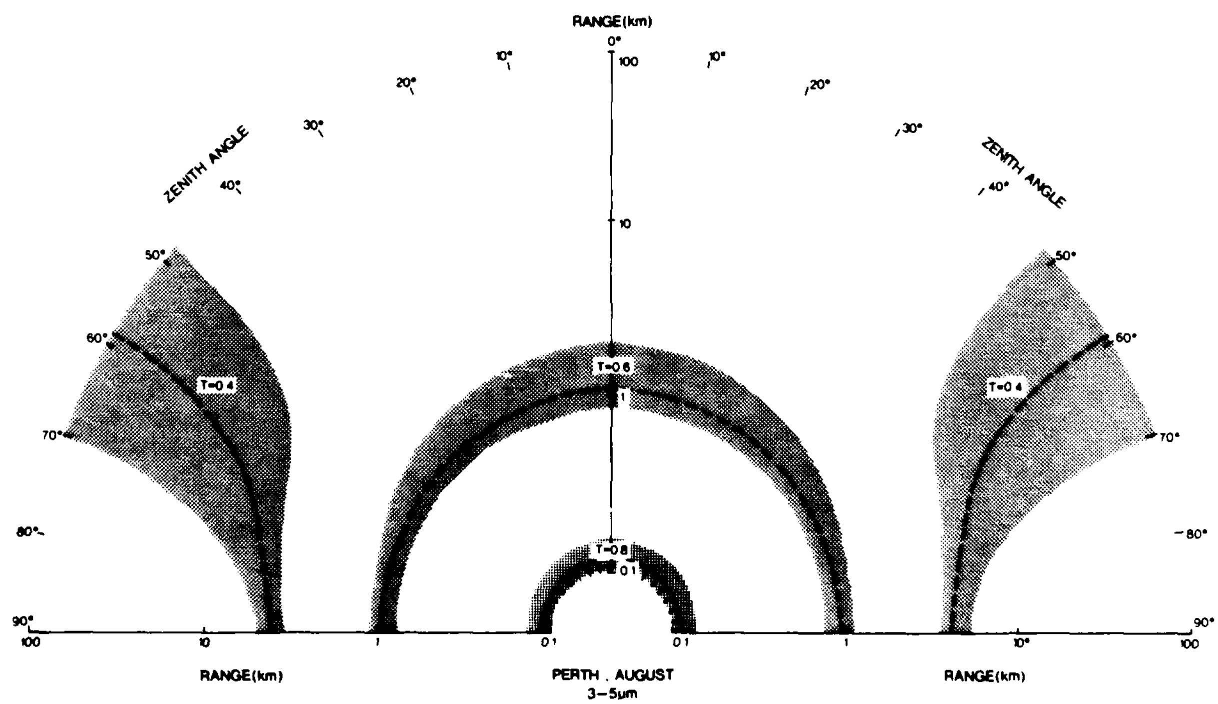
Figure IV.2(Contd.).

APPENDIX V

FIGURES RELATION TO SECTION 3.5 (RANGE)

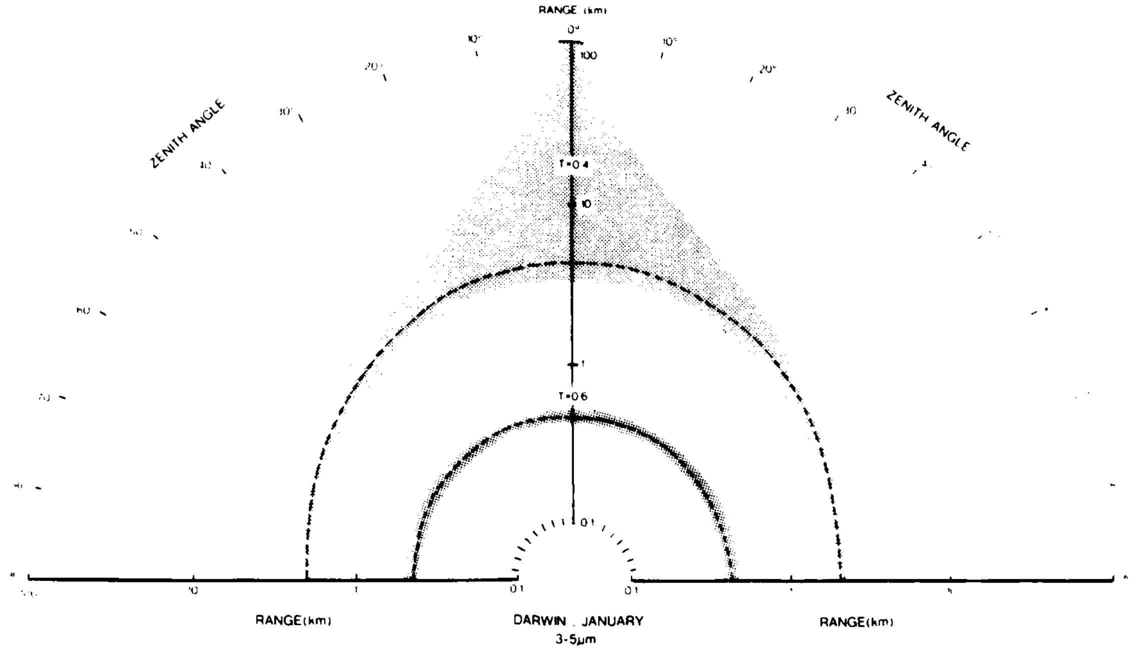


(a) Temperate Summer environment

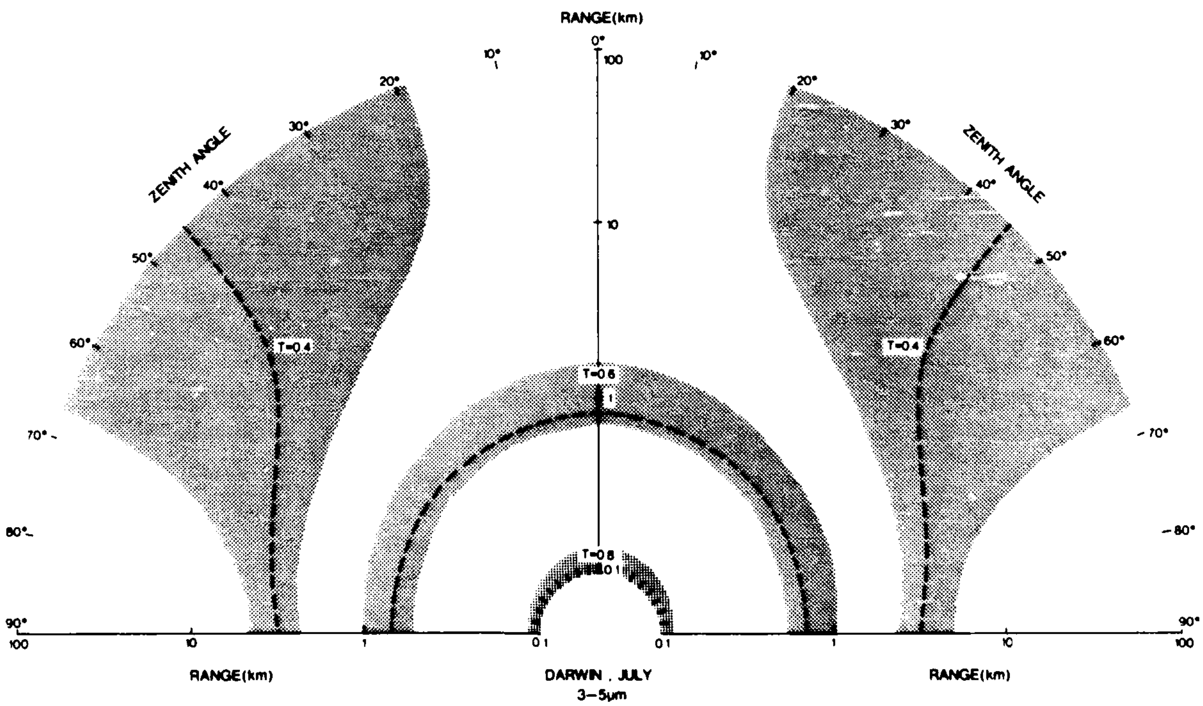


(b) Temperate Winter environment

Figure V.1 The range covered to give a particular transmittance, (3 to 5 μm), mean meteorological data (–•–), standard deviation about the mean (shaded)

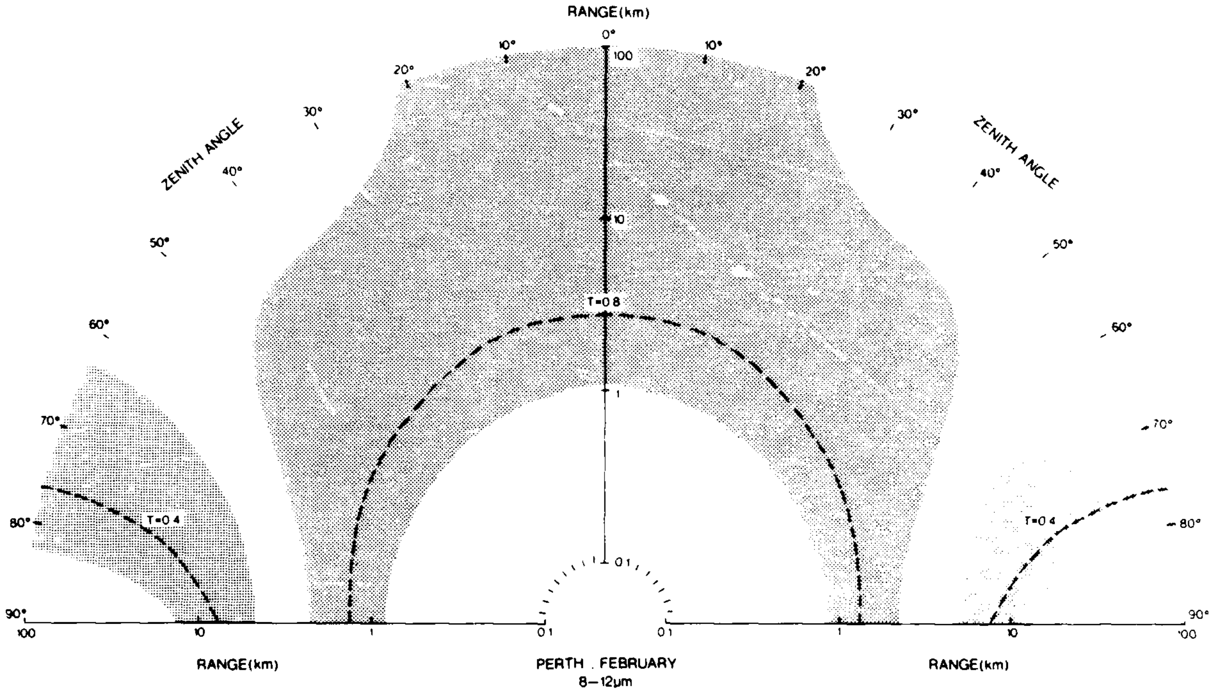


(c) Tropical Wet season environment

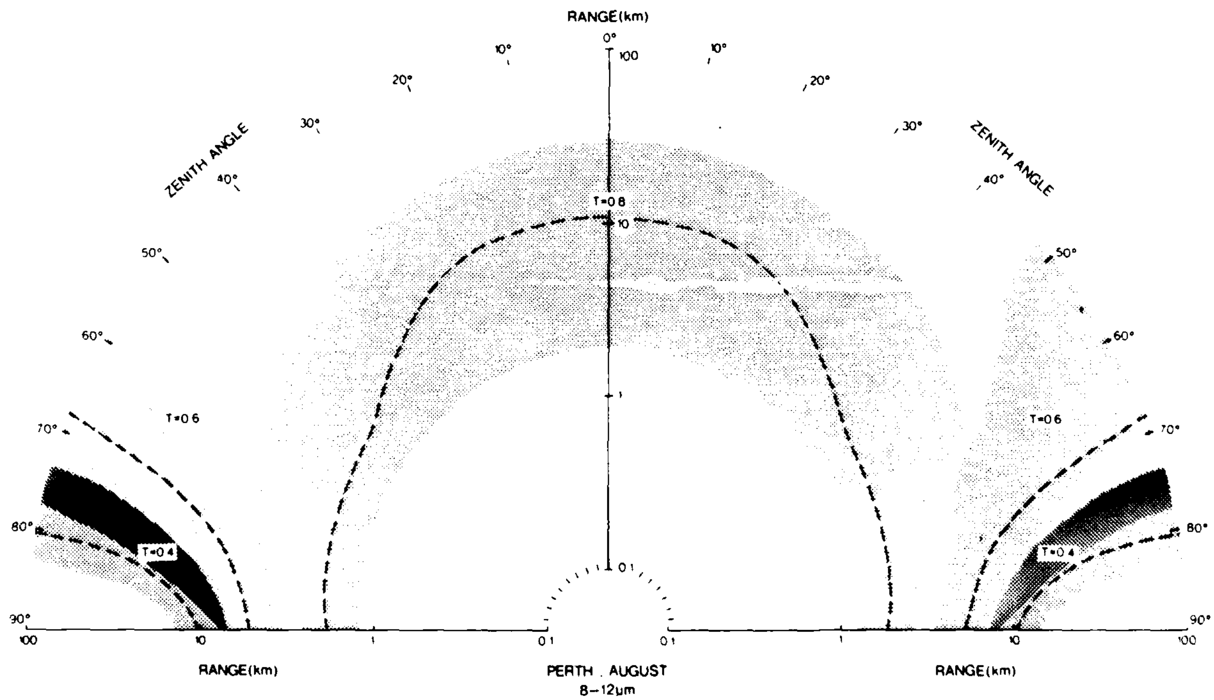


(d) Tropical Dry season environment

Figure V.1(Contd.).

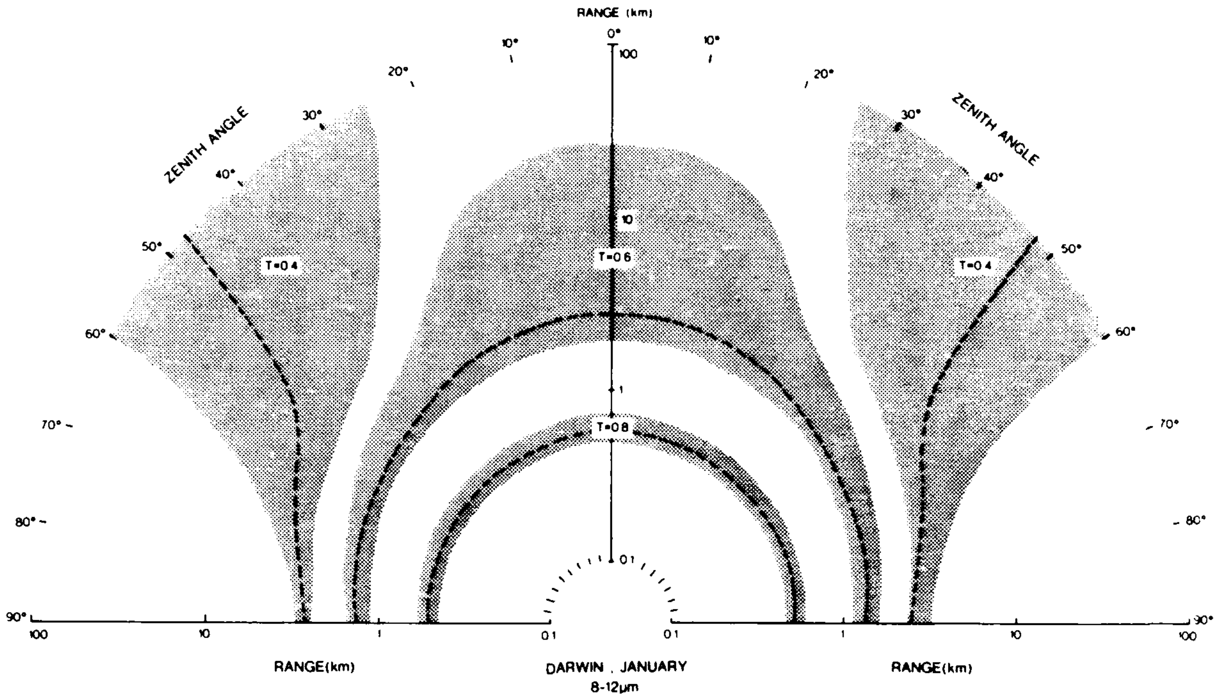


(a) Temperate Summer environment

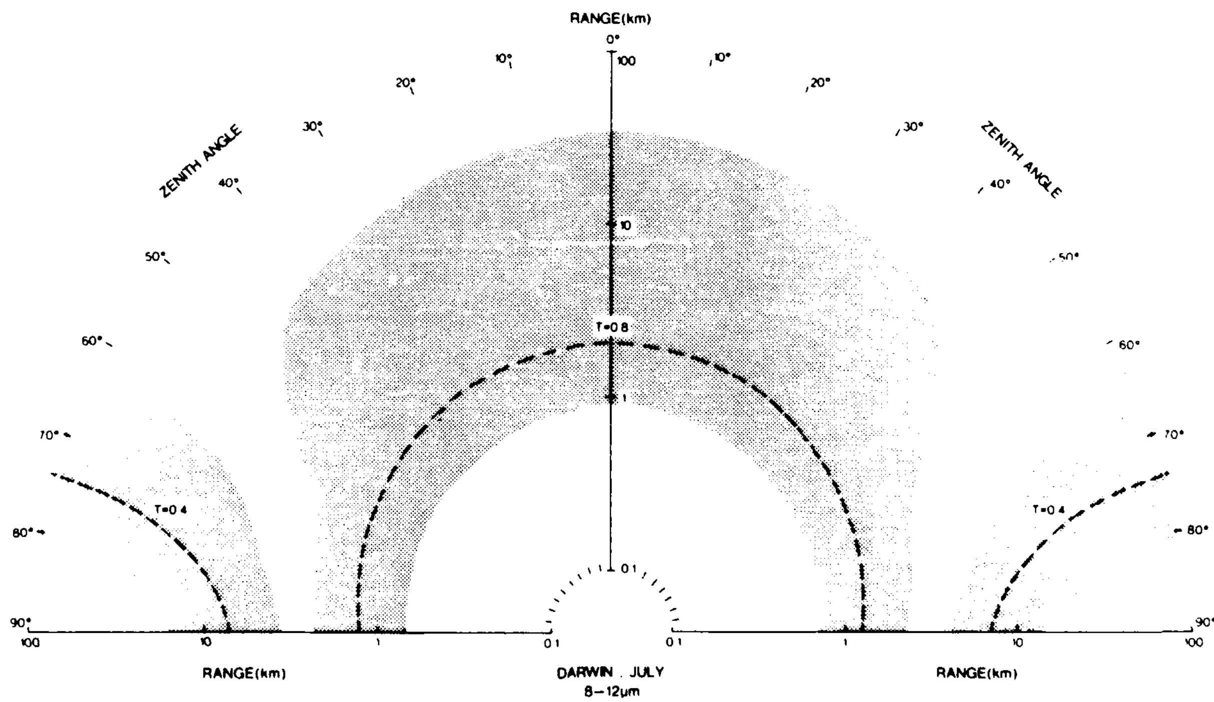


(b) Temperate Winter environment

Figure V.2 The range covered to give a particular transmittance, (8 to 12 µm), mean meteorological data (---), standard deviations about the mean (shaded)



(c) Tropical Wet season environment



(d) Tropical Dry season environment

Figure V.2(Contd.).

APPENDIX VI

MODIFICATIONS TO LOWTRAN 6

The LOWTRAN code lists self-broadening water vapour continuum absorption coefficients as a function of wavenumber for two temperatures 296K and 260K, based on laboratory measurements of Burch in the early 1970's(ref.14). Burch has since revised his laboratory measurements(ref.13) indicating that the old valves were too high. His new work presents data at 296K and 284K.

Correction factors have been derived, as a function of wavenumber, for 296K and 284K data and linearly extrapolated to 260K, within the 8 to 12 μm spectral region. The revised self-broadening water vapour continuum absorption coefficients were inserted into the data statements of the computer code.

It should be noted that since the time of these calcuations LOWTRAN 7 has been released(ref.15) which contains an analytic correction function for the above-mentioned coefficients.

This gives substantially the same results as the corrections employed in this work.

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17 SUMMARY OR ABSTRACT
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This report investigates the applicability of the standard LOWTRAN atmospheric models to four typical Australian environments and considers the effect of these environments upon the transmission of 3 to 5 μm and 8 to 12 μm radiation. It is found that the LOWTRAN model atmospheres can be useful in Australian conditions, and advice is given as to the most appropriate models to use depending upon the path and environmental conditions. The extent to which model data is used rather than real data will affect the transmittance predictions; the magnitude of this effect is given, indicating that there is particular value in measuring water vapour content (shown to be the most significant meteorological parameter) in the lowest few kilometres through which the path passes. Transmittance as a function of range (and vice versa) is considered for all slant path angles from vertical to horizontal. Graphical results are presented in full as a resource to be consulted given a particular site ad path transmittance prediction requirement. Keywords:

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